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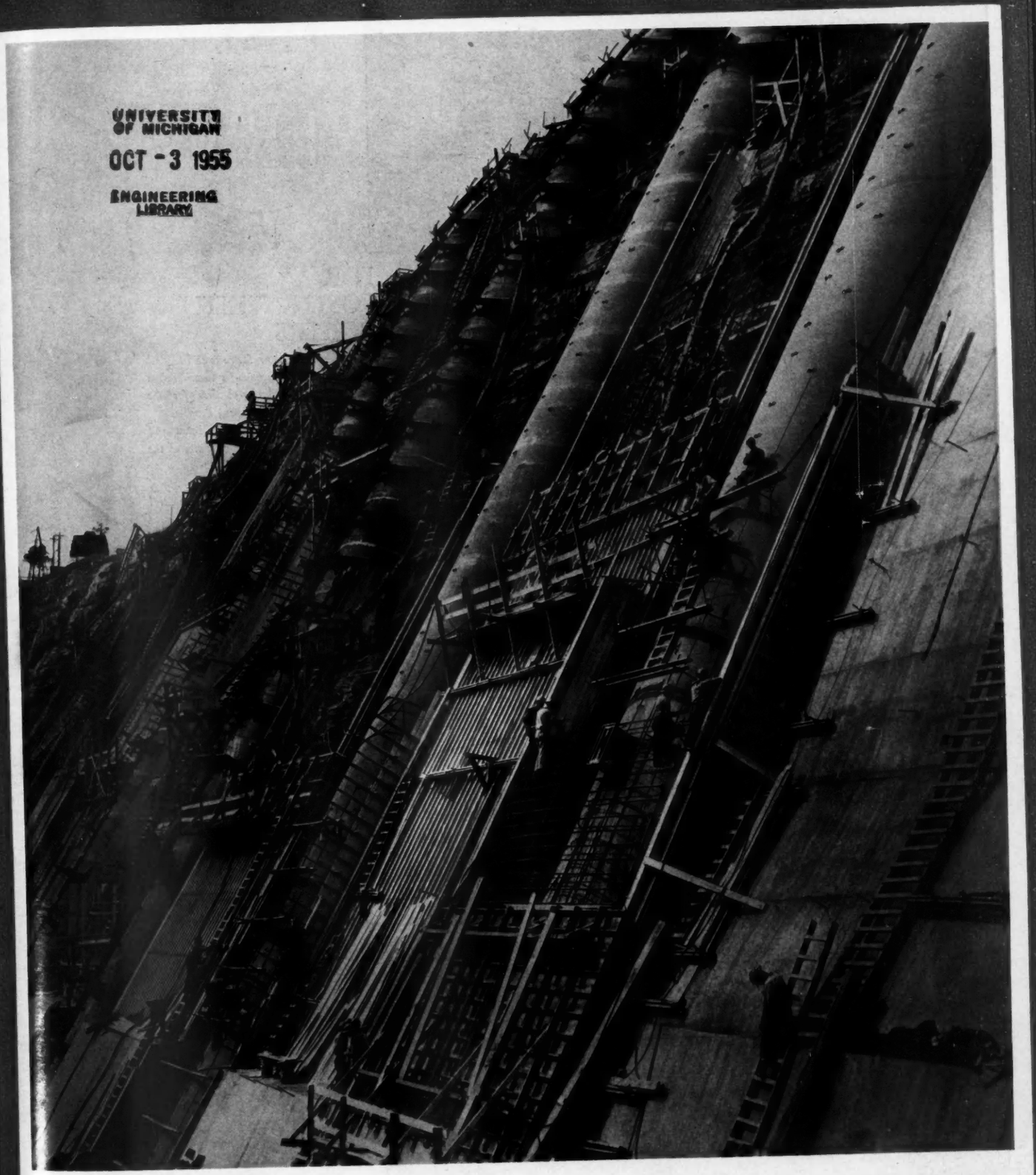
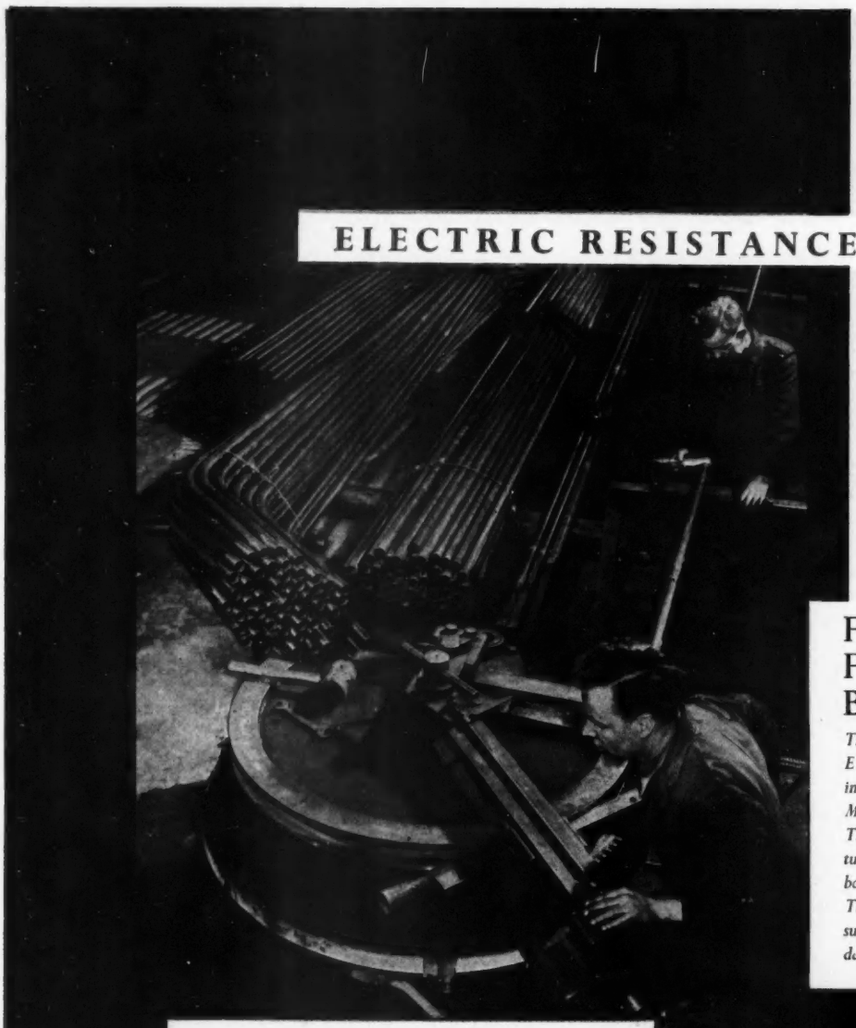


BUILDING PENSTOCKS



ELECTRIC RESISTANCE WELD TUBES

S&L

ERW

FOR
FOSTER WHEELER
BOILERS

The illustrations show Stewarts and Lloyds' ERW tubes being prepared for incorporation in two Foster Wheeler boilers for the Municipality of George Town, Penang.
The upper illustration shows the bending of tubes for the main generating bank of the boiler.
The lower illustration shows the welding of supporting lugs for superheater control dampers.

The modern type of ELECTRIC RESISTANCE WELD steel tube, as produced at our Corby Works from our own raw materials, is at least the equal in all respects of the highest quality seamless tubes. Sizes available range from 1 inch to 4¼ inches outside diameter and from 14 s.w.g. to 3 s.w.g. thick in lengths up to 36 feet, manufactured in accordance with B.S. 1654.

STEWARTS AND LLOYDS LIMITED

GLASGOW · BIRMINGHAM · LONDON

The largest manufacturers of steel tubes in Europe

ENGINEERING

An Illustrated Weekly Journal

Vol. 180 No. 4677 SEPTEMBER 16, 1955

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CONSULTATIVE LEADERSHIP

No aspect of a business is more important than the selection and promotion of its leaders. The personalities of senior and junior executives, and of shop stewards, determine the climate of work and, in the long run, make or mar the business. Selection and promotion for leadership arouse speculation and interest throughout the firm, at all levels, and are, indeed, almost the only consideration in which employers and employed evince equal and intense interest.

What are the basic principles that should govern selection and promotion? Mr. W. H. Scott is not far from the ideal when he urges the need to "search energetically for the kind of people who, if appointed to positions of authority, can discharge their responsibilities in a democratic way, through the medium of consultative leadership." He applies this need to union officials as well as managers. He sees farther than the immediate problem of making the best use of people as they are, because he believes we must also "encourage the development of educational institutions outside industry, and promotion policies within it, whereby such people can be produced as well as discovered."

These are Mr. Scott's general conclusions after a close study of "industrial democracy." His argument is set forth in the second of a series of occasional papers emanating from the Department of Social Science of Liverpool University. Democracy, he says, can be justified in principle on two grounds. First, in a democratic society the individual has the best chance of developing and utilising all his faculties. By this standard, British industry must surely be regarded as eminently democratic. There is always a demand for more men who will get out of the rut and fit themselves for leadership or greater skill. The pattern of engineering changes so rapidly to-day that there is no lack of opportunity, but it is doubtful whether there are anything like enough men who are capable of recognising the opportunities and are then ready to seize them. So high is the level of education required to-day for responsible positions in industry that unless a boy has his eyes open when he leaves school he stands little chance of making up for lost time when, a few years later, he awakens to his family responsibilities. This is a factor that was outside Mr. Scott's survey, but it is a serious barrier to the fuller enjoyment and exploitation of industrial democracy.

The second principle on which democracy can be justified is that political history suggests that democracy is the only effective safeguard against the arbitrary and self-interested exercise of power. Here, again, British industry has little to be ashamed of in comparison with the industries of any other nation.

Mr. Scott argues that industry must expand its opportunities for the exercise of self-determination and must delegate more responsibility to the rank and file. Unfortunately, the trend of development is away from giving more responsibility to the rank and file. In engineering, which leads industrial development, the tendency is to eliminate shop-floor responsibility and replace it by the responsibility which is borne in research, design and production planning departments. Even on maintenance work, where the individual operator once took a pride in the care of his machine, scientific management takes the responsibility from him. And with it, undoubtedly, goes some of the "job satisfaction" he formerly enjoyed.

The problem remains, however: "we are training youth for responsibility, only to frustrate its expectations when adulthood is reached." There is a desire, it has been found, on the part of many employees for a more consultative relationship with both their representatives and their immediate supervisors, and it is acknowledged that consultative leadership is one important component of the conditions associated with a high level of employee satisfaction and morale. In a young man's early formative years in industry the probability is that he either acquires the habit of mild grumbling (if he has potential ability he must be picked out quickly and his grumbles turned to constructive effort) or, crossing the watershed, he advances himself by his own ability. But inevitably the majority settle down to an unambitious way of life. It need not be any the worse for being unambitious (some would argue that it can denote a sound philosophy of living), but the majority who lead such a life must be allowed to derive satisfaction from it, for the community's sake as well as their's.

That, in essence, is what Mr. Scott has attempted to solve. The day-to-day executive process must be consultative. His examination of the relationships between management, unions and employees is realistic as well as imaginative, and points to ways in which consultative leadership can be steadily improved without either undermining the ultimate responsibility of managers or upsetting the delicate mechanism of trade union activities. A healthier atmosphere could also be encouraged by creating opportunities for men to take responsibility at a much earlier age than is customary to-day.

Weekly Survey

Cover Picture: *The installation of the penstocks of the Sir Adam Beck-Niagara Generating Station No. 2 for the Hydro-Electric Power Commission of Ontario is the subject for this week's cover picture. The penstocks, 492 ft. long and each 19 ft. in diameter, are being covered by a concrete blanket, and this work is shown in progress. By mid-summer, 1955, 12 units had been commissioned at the station and provision has been made for the addition of four more 100,000-h.p. units as required. The ultimate capacity of the station will be 1,828,000 h.p.*

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ENGINEERING AFTER SIX YEARS

No industry since the war has felt the pressure to channel its output to exports, to raise productivity and adapt itself to changes in technique more than engineering. The impact on the industry of changing economic conditions between 1948 and 1954 is brought out in the blue book issued last week by the Central Statistical Office on the National Income and Expenditure for this period. A new section to this publication deals with input and output analysis, which briefly analyses the importance of each industry in terms of all the others and gives a breakdown into what is termed a production account for each industry. The production account for metals, engineering and vehicles shows that total supplies between 1948 and 1954 produced by this group have increased from £2,580 million to £3,520 million at factory values. This is an increase of 36 per cent. Over the same period the imports of this group have changed from only £50 million to £55 million.

There has been an absolute increase in the production for each group of main users but there has been quite a noticeable shift of emphasis in the relative importance of different channels of outlet. Goods for consumers' expenditure increased over the period from 7 to 9 per cent. of total value; expenditure on defence advanced from 4 to 11 per cent.; goods for capital formation fell from 30 to 25 per cent.; exports fell from 30 to 28 per cent.; and other domestic uses, which includes investment in stocks and work in progress, declined from 29 to 27 per cent. Over these six years there had thus been a shift away from export and capital formation towards consumer goods and defence work. A guess as to what has happened since the end of 1954 would be that the increase in defence work has slackened off but that the proportion going to consumers' expenditure has increased, some of the increase being shared by capital formation. These figures do show, however, the effect which high demand in the consumer goods market is having on the products of the metal and engineering industries through the years.

Another table shows the amount of what is called the "primary input" of imports, income from employment, gross profits and taxes necessary to produce £100 of final demand in each major group of industries. In the case of metals, engineering and vehicles the import content is only £12, which is among the lowest of the ten groups. The highest import content is, incidentally, textiles at £38 and the lowest is the public utilities at £4. Expansion of the engineering industry therefore puts a much less than average strain on the import bill.

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THE CASE OF COHENS

Prosperity brings its own problems. Many engineering companies are in the position of having full order books and plans for expansion but they are faced this autumn with having to absorb higher fuel costs, a rise in the wages bill and uncertainties which may develop in their customers' minds about their development plans as the credit squeeze develops. These problems face George Cohen Sons & Company, Limited, in the early stages of a new financial year, according to the chairman's statement. The financial year ended March 31 last closed with a group turnover of just over £19 million, which was an increase of 7·5 per cent. on the year before.

In his review of the year's operations Mr. Cyril Cohen refers to the company's efforts to achieve higher production with a minimum increase in manpower, this with special reference to the subsidiary K. and L. Steel Founders & Engineers, Limited, at Letchworth. The labour problem is, of course, particularly acute in Hertfordshire, with expansion going on in established concerns and a group of new towns developing. The extensions to the foundry are now nearing completion but this subsidiary experienced a drop in profits despite record turnover in both the steel-founding and engineering divisions, owing to the high costs of production, not all of which could be passed on to customers. T. C. Jones and Company, Limited, has outgrown its Woodlane capacity and a new site is being prepared at Neasden. A policy of increased mechanisation is going forward at the Colchester Lathe Company, Limited. The machinery division has had a successful year, as would be expected from an activity which serves a large number of customers in the engineering industry, and the hire fleet of contractors' plant has operated at full capacity.

The company has overall suffered no fall-off in orders due to the recent strikes and rising costs, but it clearly takes a serious view of the adverse potentialities of the credit squeeze. The group is operating on a high level of activity but the growing burden of costs has made the board budget for a somewhat smaller profit than that which was earned in the last complete financial year.

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TECHNICAL AID FOR THE U.S.

An agreement has been signed between Taylor Brothers and Company, Limited, and the American Rolling Mills Corporation (as reported in our Commercial column) for the British company to give technical assistance to the latter to enable the American company to incorporate the principles and designs of Taylors' Trafford Park forge plant in their new installation. Taylor Brothers are a subsidiary of the English Steel Corporation and the remarks last week of the managing director, Mr. R. G. H. Taylor, summed up the situation: "The agreement will bring the firm hundreds of thousands of dollars. It is a source of great satisfaction to know that we have the Anglo-American Productivity Council working in reverse."

There is one more point to be added to his remarks. This agreement sets the seal on the success of Taylor Brothers project. Towards the end of 1952 (two articles on the new forge appeared in ENGINEERING of December 5 and 12, 1952) it appeared to be a bold decision to instal a highly-mechanised forge for the continuous production of railway wheels. The plant included a rotary-hearth furnace which was believed to be the largest in Europe, an 8,500-ton forging press, two other large presses and a rolling mill for forming the rim. The original target was to produce an average of 60 wheels an hour with 50 per cent. of the manpower used in the old plant. A high degree of mechanisation was introduced with the new plant, including the mechanical handling of steel blocks between the furnace presses and mill.

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REPORT ON WROUGHT COPPER

The Monopolies Commission's report on the supply and export of certain semi-manufactures of copper and copper-based alloys was published last week. The findings cover six main categories of wrought copper and copper alloys, namely plate, sheet, strip, rods, wires and tubes. There are 150 manufacturers concerned, of which 70, who account for over 75 per cent. of total production, belong to one or more of the 12 trade associations most of which are in turn members of the British Non-Ferrous Metals Federation.

The report considers that restrictive practices exist in both the home and export markets. The principal arrangements in the home market to restrict competition are minimum price agreements and certain supporting arrangements, including uniform terms and conditions of trading and the granting of quantity rebates or "loyalty discounts." In the export market the Federation and two export groups are signatories to the "Lausanne Agreement," signed in 1946, under which signatory manufacturers agree to observe each other's home trade prices in each other's domestic markets and, with certain exceptions, an agreed price list in most other markets. Agreements also exist requiring members of federated associations and export groups to charge common minimum export prices. The Commission consider that the minimum price arrangements keep costs and prices up and that they are against the public interest. These arrangements and others ancillary to them should, in the opinion of the Commission, be abrogated. They think that the effect of the Lausanne Agreement is to keep home prices up and that this outweighs any possible advantage manufacturers may have so far as direct exports are concerned. The effect of minimum prices for exports is difficult to assess but the Commission consider that if these arrangements are not brought to an end at the same time as the common minimum prices in home markets, they should be further examined in two or three years time.

In response to the Commission's report, the British Non-Ferrous Metals Federation has issued a ripost under six headings. These claim that average profit margins have not been high in the industry; that it has to deal with powerfully organised customers and raw material suppliers; that there are no private courts, no stock lists, no collective boycott, no retail price maintenance and no quotas; that the inquiry did not result from customers' compaints; that there is competition in price and quality within the industry and competition from outside from substitute materials; and that co-operation in pricing has made possible important progress in research and development. The Federation is not on strong ground in quoting average profit margins, for monopoly usually goes with "reasonable" profits rather than high ones—trade agreements are designed to perpetuate the quiet life. They are on much stronger ground if they can argue effectively that they are caught between suppliers and customers who are more highly organised than themselves.

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STEEL BID BY FRANCE

The French steel industry has now shown its hand so far as the expansion of steel-making capacity is concerned up to the end of 1957. Its plans are contained in a document published by the Iron and Steel Modernisation Committee of the Planning Commission which advises the French Prime Minister on development plans for French industry. The committee's proposals are set out in an article in the August issue of the *Monthly Statistical Bulletin* of the British Iron and Steel Federation. Under the 1946 plan, which came to be known as the Monnet Plan, the task was set the iron and steel industry of modernising rather than expanding its capacity. Under this plan, output was below 10·9 million metric tons in 1942 compared with the 1952-53 target of 12·5 million metric tons. It was even lower in 1954, while the development plan tended to lag and capital expenditure was higher than originally expected.

The second plan is concerned with providing sufficient steel to meet the National Plan's objective of a 25 per cent. increase in France's national product in five years and a 30 per cent. increase in industrial production. The steel plan is intended to cover requirements up to 1957 and to take into account the results arising from the establishment of the European

Coal and Steel Community. The basic aim of the plan is to strengthen the competitive position of the French steel industry, to reduce costs and to raise the quality of its products, especially basic Bessemer steel. The steel plan has been worked out in detail both for new capacity and supplies of materials. When completed it is expected to have cost £225 million and should enable France to produce, by 1957, 14·3 million tons, in addition to 2·4 million tons of pig iron for non-steel purposes.

The existence of the Coal and Steel Community adds a complication. France has benefited by gaining access to German markets since the formation of E.C.S.C., but its home market has become increasingly vulnerable. At the moment France's steel industry is booming and record levels of output are being established. For certain basic Bessemer qualities French steel prices are the lowest in E.C.S.C., but the margin is not great and customers are easily persuaded to favour open-hearth quality, in which France is at some disadvantage. In addition French steel prices have been kept low at the expense of gross profits, out of which development can be financed. The supply of capital from outside the industry is therefore critical and on the source of this capital the report is not very forthcoming. The very fact that France is a member of E.C.S.C. means not only that its steel products are open to competition in a common market but that the prospects of attaining the targets must take into account the development plans of other countries' steel industries within the pool. In the recent past some of these countries have shown greater ability to hit their targets than has France.

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PEAK EMPLOYMENT

There were 22·95 million in civil employment at the end of July. This was 50,000 more than at the end of June and 290,000 more than the year before. It is therefore the highest peacetime figure ever recorded. Owing to the number of school-leavers coming on to the labour market early in August there was an increase of 15,000 in unemployment. Even so, the number unemployed on August 15 was only 0·9 per cent., compared with 1·1 per cent. in August, 1954. Thus, for the second month in succession, unemployment has been below 1 per cent.

In metal manufacture and in engineering, metal goods and precision instruments there was a small decline in numbers employed in July compared with June. In metal manufacture there were 569,000 employed at the end of July compared with 570,000 at the end of June and 571,000 at the end of May. Compared with July, 1954, however, employment had increased at the end of July by 3 per cent. A very similar trend is apparent in the engineering section, where employment at the end of July was 5 per cent. up on the year but slightly down on May and June. By and large, however, the trend over the summer months has been for the consumer-goods industries and services (with the exception of textiles, which continue to be affected by the movement of workers out of the Lancashire cotton industry) to attract substantial numbers of workers while the capital goods industries have been shedding small numbers. Here is one more symptom that the consumer-goods industries are at present driving the economy rather than the capital goods.

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GAS FROM OIL

One of the difficulties of oil companies is that the fractions into which crude oil can be converted are of nearly inflexible proportions. A demand for one fraction means production of other fractions which may or may not be in demand. A very satisfactory method of resolving this problem has been devised by the British Petroleum Company, Limited, and the South Eastern Gas Board; oil products from the Company's Kent oil refinery on the Isle of Grain are to be converted into town gas by oil gasification plants. The gasification plants can accept a wide range of oil products for conversion into gas, and therefore British Petroleum can rid themselves of their surpluses at any time. The agreement signed between the two organisations is for a period of 20 years, and is intended to lead to a close working relationship in order to use whatever oil products are available to the best advantage of both parties.

The British Petroleum Company are granting a long lease of a site which will be sufficient for the construction of oil gasification plant up to a daily capacity of 80 million cub. ft. If the plant is developed to this extent it will be equal in output to the largest gas-works in the area. In the first stage gas will be produced on the scale of 15–20 million cub. ft. a day, with a saving of about 300,000 tons of coal a year. The quantity of oil to be used in the first stage is estimated to be 60–70,000 tons a year. Orders will be placed by the Board as soon as possible for four oil gasification units and these should be completed in two to two-and-a-half years.

Mains will be laid from the Isle of Grain to Strood in Kent to feed the gas into a trunk main system through which gas will be distributed south of the Thames from Sittingbourne in the east as far as Guildford in the west. The new plant will be the first in the country to use oil products on a large scale as the only material for gas production.

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EXPANDING TRAFFIC

The average increase in the number of mechanically propelled vehicles on the roads of the United Kingdom, compared with pre-war conditions, is 38 per cent. This is the first result gleaned from the traffic census arranged by the Ministry of Transport and Civil Aviation and carried out during one week in August. Counts were made at 5,830 stations on trunk and class 1 roads from 6 a.m. to 10 p.m. each day and there were also night counts at selected points during the intervening eight hours. While the full results are being studied and summarised, sample counts from 300 stations have been analysed.

The overall increase in traffic of 38 per cent. is made up of 100 per cent. more goods vehicles, 41 per cent. more buses and coaches, and 19 per cent. more private cars. But the number of pedal cycles was a third less than in 1938—the occasion of the last similar national census—and horse-drawn vehicles were very few.

The percentage of goods traffic passing all points amounted to 26 per cent. of all mechanically propelled traffic, compared with 18 per cent. in 1938. Over half the total, however, was still made up of private cars. As might well be expected the number of goods vehicles fell to about one-half on the Saturday and to less than one-quarter on Sunday. But an increase of 50 per cent. more private cars on Saturday and 40 per cent. on Sundays made the volume of mechanical traffic roughly 20 per cent. heavier over the week-end than during the week.

Commenting upon the figures, the British Road Federation were quick to note that the Minister of Transport has recently admitted that roads have neither been improved nor extended in the 16 years that have elapsed since the pre-war years.

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SAFETY FOR CAR OCCUPANTS

With the rapid increase in the number of vehicles on the road, vehicle occupants are forming a higher proportion of total casualties, but their safety has had comparatively little attention. Car manufacturers feared that undue emphasis on the hazards of motoring would be bad for sales.

Now Ford of America have taken the initiative, introducing safety features inspired by published medical papers on crash injuries, backed up by its own experiments in which cars with dummy occupants have been crashed under remote control. Their safety measures are based on the premises that 59 per cent. of crashes are at the front of the car; the danger of death or serious injury is doubled when the doors open and the occupants are thrown out; and many injuries are caused by contact with steering columns, instrument panels, and driving mirrors.

The features adopted to minimise these injuries are: dished steering wheel to distribute the load on the driver's chest, and prevent contact with the column; padding of instrument panel and roof above screen; mirror with non-shatter backing, stronger door locks and seat anchorages; and optional lap straps to withstand a 4,000-lb. load.

Safety for car occupants is now being built up into a major selling feature; Continental manufacturers are already offering dished steering wheels, padded instrument panels and non-shattering mirrors, and Britain must be prepared to compete. Lieut.-Colonel Stapp, famous for his rocket sled experiments into the capacity of the human body to withstand very high accelerations and decelerations, is quoted as saying that the metal in the front half of an American car compresses too easily. Better impact absorption may be obtained from the European type of unit structure, rather than the American separate chassis, but a major objective must always be to prevent the engine being driven back into the passenger compartment.

Lap straps seem a doubtful asset; on a small car they would allow the occupants to "jack-knife," smashing their faces against the instrument panel. Better to have a light shoulder and waist harness such as those used by glider pilots. Ford of Dagenham offer a good shoulder harness, but report a very small demand so far. This is a pity, for a driver cannot even use his brakes to the full without the risk of injuring passengers if they are not strapped in. People have to be sold safety like any other commodity, and the pressure is now beginning.

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AN INNOCENT AT FARNBOROUGH

Apart from the sensational—the fly-past of superb and awe-inspiring aircraft, test-pilot Falk rolling the huge Avro Vulcan, Zurakowski keeping his promise to fly the twin-jet-engined Avro CF-100 backwards, an R.A.F. sergeant being projected explosively into the air by the Martin-Baker pilot-ejection seat, and a remarkable display of aerobatics by four Hawker Hunters flying against a clear sky as one aircraft—apart from these, there is much to see at Farnborough for someone visiting the S.B.A.C. display for the first time.

There is, for example, a very large indoor exhibition. Here the visitor may see the latest aero engines, the light-weight Bristol Orpheus which powers the Folland Gnat, and its mighty brother the Olympus; the world's first high-powered by-pass turbojet—the Rolls-Royce Conway; or the unusually shaped Napier Oryx which produces gas for driving helicopter blades by tip-jet reaction.

If the visitor is not a specialist in aeronautics he may come upon devices or techniques with applications in his own trade or industry—a novel type of riveter (Aviation Developments, Limited), for example, designed for one-handed operation in awkward places; a fluorescent flaw-detection ink (Manchester Oil Refinery Limited); a process of precision investment casting (" Mercast " frozen-mercury process—Sankey-Telcon Limited); a *p*H-factor controlled polish (Valay Industries Limited); a method of sandwich construction employing cone-shaped spacers (Essex Aero Limited); a special welding controller (W. H. Sanders, Limited); or a new alloy, Nimonic 100, which can be used at temperatures 30 deg. C. higher than was possible with earlier members of the series (Henry Wiggin and Company, Limited).

But if the visitor is really concerned with finding something new, his best plan is to avoid the brightly printed brochures and look for the type-written hand-out sheets, since a product is surely new if its maker has not yet had time to issue a fully documented description.

THE PEACEFUL USES OF ATOMIC ENERGY

A SURVEY OF THE GENEVA CONFERENCE

By Sir John Cockcroft, K.C.B., C.B.E., F.R.S.

The Geneva Conference on the Peaceful Uses of Atomic Energy organised by the United Nations Organisation has been a remarkable experience for those fortunate in participating. It was attended by 1,400 delegates, and observers from 73 countries. Over 1,000 papers were prepared for the Conference of which 450 were read.

The main weight of the papers in the sessions on reactor technology and chemical and metallurgical technology came from Britain, Russia, and the United States, though there were many valuable contributions from other countries. The Conference led to a lifting of the veil over the atomic energy programme of the U.S.S.R. and coincided with the coming into effect of a revised declassification policy of Britain, Canada and the United States, decided in principle nine months ago.

So we heard a large number of valuable papers on research reactors and power reactors and their associated technology. From the 900 or so possible types of power reactors in Dr. A. M. Weinberg's (Oak Ridge National Laboratory, U.S.A.) classification about twelve have been selected for construction in experimental or prototype form by five nations. Thus, graphite-moderated reactors using gas, water or liquid sodium for cooling are being built by Britain and France, Russia and the United States, respectively.

U.S.S.R. ATOMIC POWER STATION

Water-moderated reactors using solid fuel are being studied in four types using light or heavy water, and in designs in which the water boils and is transmitted directly to a turbine, or in which the water circulates through a heat exchanger to raise steam. Homogeneous thermal reactors were described in at least three forms, while experimental fast reactors are being built by both the United States and United Kingdom.

Professor Blokhintsev, who is head of an institute of the Academy of Sciences devoted to reactor development, described the first Russian water-cooled graphite-moderated power station which has been operating for a year and produces 5,000 kilowatts of electricity. The power reactor was designed on severely practical lines with no regard for neutron economy since uranium fuel containing 5 per cent. of uranium 235 enclosed in stainless-steel tubes constitutes the fuel element. So fuel costs are very high and the regeneration of secondary plutonium fuel is low.

The reactor has proved to be very reliable in operation and is providing experience from which a 100-MW reactor is now being built. This reactor will also use highly enriched fuel and is expected to produce power at a cost of 10-20 kopecks per kWh as compared with an average price for conventional stations of 10 kopecks. Other types of power reactors are being experimented with, including fast reactors, but the state of development appears to be behind the United States and the United Kingdom.

WIDE RANGE OF REACTORS IN THE UNITED STATES

The United States papers on power reactors and nuclear technology show a very broad development in this field. Very detailed papers were presented on their pressurised-water reactor which is to develop over 60 MW, their sodium-graphite reactor developing 75 MW, their boiling-water reactor developing 180 MW, the homogeneous aqueous and liquid-metal fuelled reactors, and the sodium-cooled 62-MW (fast) experimental breeder reactor. These papers were supplemented by most interesting models in the exhibition at the Palais des Nations, together with specimens of the fuel elements to be used.

These reactors form part of the United States five-year programme of experimental and demonstration power reactors which will be completed by 1960, so that by then the United States will be generating 700 MW of electricity from nuclear stations.

Britain presented papers on the engineering details of the Calder Hall graphite-moderated gas-cooled reactor and the Dounreay fast reactor. Models of these reactors were shown in the exhibition together with a most interesting colour film on the building of the Calder Hall reactor. The United Kingdom also contributed many papers on reactor technology.

TWO ATOMS FOR ONE

One of the most interesting papers described the results obtained with the zero-energy fast reactor—Zephyr—which showed that in a plutonium-fuelled zero-energy fast reactor, for each plutonium atom destroyed in the core, two new plutonium atoms are produced in the blanket. Fission of the uranium 238 in the blanket plays an important part. The full-sized fast reactor will not realise the full theoretical breeding gain, owing to absorption of neutrons by coolant and other materials. Nevertheless, high gain factors seem assured, and Dr. W. H. Zinn, Director of the Argonne National Laboratory, U.S.A., predicts a breeding gain of 60 to 70 per cent. with the United States experimental breeding reactor, leading to a time to double the fuel investment of 5 to 6 years.

The aqueous homogeneous breeding reactor using the thorium-uranium 233 fuel cycle was predicted to have a breeding gain of 10 to 15 per cent., together with very high outputs per kilogram of fuel and comparatively low capital costs. The uranium 238-plutonium fuel cycle does not promise breeding in the thermal region. Since thorium has also favourable properties metallurgically, its use in thermal reactors seems likely to be important in the second decade.

NATIONS AGREE ON NUCLEAR DATA

Our best view of Russian nuclear technology was in the field of nuclear constants. The nuclear data obtained by Russia, Britain, the United States and France have all been plotted on a common basis and show very good agreement, indicating that U.S.S.R. techniques and instruments are as highly developed as those in the United Kingdom and the United States.

The papers on the economics of nuclear power showed a general consensus of opinion that capital costs of nuclear power stations will be appreciably higher during the next decade than those of conventional power stations. Typical values were £120 per kilowatt for a 150-MW gas-cooled graphite reactor; 250 dols. (approximately £90) per kilowatt for a 250-MW boiling heavy-water reactor; 300 dols. (£108) per kilowatt for a 75-MW sodium graphite reactor. The first figure is based on experience in constructing Calder Hall, the others on design studies only.

Fuel costs were predicted to be lower than for conventional stations but this depends largely on the " burn up " of the uranium 235 which is achieved. Prediction of heat extraction per ton of uranium varied from the equivalent of 10,000 tons of coal to more than three times this figure. But little experimental evidence is yet available.

The figure for the overall cost of nuclear power depends a great deal on the interest rate assumed. The United States use high capital charges—of the order of 12 to 15 per cent., and their forecasted overall production costs during the next decade lie between 7 and 10 mils (1 mil is about 0·09*d.*) while the great bulk of their power is generated at about 5 mils. In Britain, nuclear power is quasi-competitive.

The forecasts of the proportion of electricity to be generated by nuclear power in 1975 varied, from 40 per cent. in Britain to a United States figure lying between one per cent. and 15 per cent., depending on whether costs are 9 mils a unit or 6 mils a unit at that time. The Canadian position seems to be rather similar. Forecasts of the usage in other countries by 1975 varied greatly, depending on the amount of hydro-electricity still to be developed and its capital cost and location. Most Western European countries will not require appreciable amounts of nuclear power before 1965.

Dr. Bhabha's paper on India's energy requirements showed that 80 per cent. of the energy comes from the burning of dung. The energy consumption per head is one-tenth of that of Britain and electricity consumption one-eightieth. This is planned to increase seven-fold by 1975, so electrical capacity will have to increase from 3½ million kilowatts to 25 million kilowatts. The undeveloped hydro-electric capacity of 25 million kilowatts could provide most of this but there are some areas far from hydro-electric sources where thermal power stations are at present used, and here nuclear energy will play a part. India is especially interested in the use of thorium.

10-MW PLANTS FOR REMOTE AREAS

Papers on the power requirements in other " under-developed countries " showed a need for power reactors developing about 10 MW of electricity. These may also find applications in remote mining areas. Power costs in many of these areas are already much higher than normal costs—up to four times higher. Power from small units will necessarily be higher in cost but papers presented by the United States suggest that a reactor of the boiling-water type could probably produce power at 15 mils, which is almost competitive with commercial 10-MW power stations.

It appears, however, that a much more detailed " market survey " of the power needs and requirements of these countries is required before we can assess the volume of applications in the next two decades.

The position at the end of the century is easier to assess since the economists and statisticians agreed in predicting a minimum energy requirement of 7 or 8 billion (10^9) tons of coal equivalent by the year 2000, of which half would be required for generating electricity. Hydro-electricity is predicted to supply 1 billion tons equivalent and and it is hoped that nuclear energy would by then be able to do the work of 2 to 3 billion tons of coal a year. The forecast of United Kingdom requirements for nuclear energy at that time is about a tenth of this figure.

Papers on the occurrence of uranium and thorium suggest that in the 1960's plenty of fuel will be available at a cost of about 10 dols. a pound. Supplies of at least one million tons were reported to be available and if, by the end of the century, breeding is achieved, only a few thousand tons of uranium and thorium a year are required to undertake the task predicted by the economist.

RADIATION HAZARDS

The biological sessions discussed the hazards of radiation to workers in the atomic energy industry and to the general public. The excellent work done by the International Commission on Radiological Protection in determining safe levels of radiation and safe amounts of radioactive materials was described and it was agreed that these recommendations ought to be incorporated into world-wide codes of practice. The World Health Organization undertook to help countries new to atomic energy development.

In general the United Kingdom delegation obtained most benefit from the United States papers on reactors since these contained a great deal of information which has not hitherto been available to us.

The United States are developing reactors on a much broader front than we have been able to do with our limited resources, so these papers will be of great benefit in helping us to decide our policy on reactor development beyond the Stage I Calder Hall type. The papers will have been of even more value to British industry generally.

The Russian papers have not provided us with much technological information which we can use but they have been of value in showing the scale and quality of their development. It is clear that they have deployed a very much greater effort than the United Kingdom and approaching that of the United States. We were given to understand in private discussions that the proportion of university graduates taking science and technology is about double our proportion and that the university numbers are at least five times United Kingdom numbers. Their great resources are illustrated by the wealth of instrumentation of their laboratories on the one hand and by the fact that they will shortly possess the two largest nuclear accelerators in the world, the largest containing 36,000 tons of steel. In this field of modern physics using high-energy accelerators Britain is now far behind.

The Conference has been more successful than we had dared to hope from such a large gathering. It has brought together East and West after a long period of separation in the physical sciences. It has been a meeting ground for innumerable friends from all parts of the world. It has enabled us to discuss how best we can help other countries and has done a great deal to re-establish the normal pattern of communication in the scientific world.

Editor's Note: The Secretary-General of the United Nations, Mr. Dag Hammarskjöld, has recently announced that the complete proceedings of the International Conference on the Peaceful Uses of Atomic Energy, held in Geneva in August, are to be published in 16 volumes of approximately 500 pages each. These volumes, which will include all the papers submitted (over 1,000), will be published by the United Nations in several languages; the English edition should be available at the beginning of 1956.

A special pre-publication price of £39 or the equivalent in other currencies for the full series of 16 volumes has been established, and will apply to all advance orders received up to December 31, 1955. Orders for the full set or separate volumes (the prices of these to be announced later) may be placed with any sales agent for United Nations publications, including H.M. Stationery Office, P.O. Box 569, London, S.E.1.

TECHNICAL EDUCATION

COLLEGES AND POLYTECHNICS AS SOURCES OF ENGINEERS

In this article a selection of technical colleges and educational institutions is considered with special reference to the courses offered and the standards reached. Mention is also made of the distribution of such establishments and their part in relieving the shortage of technologists.

The shortage of trained technical and scientific staff members in British industry is, at times, attributed to inadequate facilities for producing them and various proposals for the extension and multiplication of higher technical educational institutions are under discussion. A study of our advertisement columns will make it clear that although there is heavy and constant demand for graduates, there is equally one for youths of Higher National Certificate standard. The graduates who swarm in American manufacturing industry, and to whom much of its success is attributed, have not, in general, attained an educational standard equivalent to that of a British graduate; their level is that of a National Certificate or, at best, a Higher National Certificate. There may well be room for an increase in the number of technical-educational institutions in this country, but a study of a number of prospectuses recently received makes it clear that facilities for education at what may be called the technological level are extensive and widespread. Even were the material available, a review of activities of the whole of the technical colleges and technical schools in the United Kingdom would be an impossible task. The samples chosen, entirely on the basis of the fact that particulars are immediately available, may, however, be taken to indicate the type of educational institution existing in every manufacturing centre in the country.

SMALL-TOWN FACILITIES

An example of courses leading up to the Ordinary National Certificate and to Higher National Certificate is provided by the Mid-Essex Technical College and School of Art at Chelmsford. Students, who must be over 16 years of age, may if necessary take these courses entirely in evening classes, but in view of the release facilities now provided by most engineering firms, many will probably take the part-time day and evening course. Attendance at evening classes one or two days a week is required. The Ordinary course takes three years and the Higher five. Mechanical, electrical and production engineering courses are available. In addition, there are post-Higher National Certificate classes in industrial administration and mathematics and a special two-year evening course for students preparing for the entrance examinations of the major engineering institutions.

This example of the educational facilities provided in a town which has important engineering interests but which is not one of the great industrial centres of the country is in no way unique. Probably a youth situated in any part of the country, except possibly in a remote rural district, will find himself within reach of an institution which, if he takes advantage of it, will qualify him as a technician in the sense in which the word is being used in this article. Progress to a higher professional status will depend on the individual rather than the institution. As further examples of towns, not great cities, in which provision is made for the attainment of Ordinary and Higher National Certificates, York and West Hartlepool may be mentioned. The technical colleges of this city and county borough provide part-time day and evening classes leading up to these certificates. The prospectus of the College of Technology of the City of Portsmouth indicates that courses are provided preparing for the Higher National Certificate or the external degree of London University.

In London and the surrounding district it is natural to find that provision for technical education at every level is widespread. The South East London Technical College, for instance, which serves a densely-populated area, provides instruction leading to the attainment of National Certificates, but also, in courses dealing with such subjects as electrical installation work, offers training leading up to the certificates of the City and Guilds of London Institute. The multifarious activities of this latter institution are to a considerable extent concerned with the production of craftsmen rather than technicians. Courses are held dealing with such subjects as sheet metal work, instrument maintenance, refrigeration practice, mechanical engineering inspection and engineering planning, estimating and costing. The word " craftsmen " above is used in a broad sense. Even for such a subject as sheet metal work the course lasts four years and covers theoretical as well as practical instruction.

An engineering inspector or one concerned with planning, estimating and costing would certainly not normally describe himself as a craftsman, but the word is justified in view of the fact that the courses are concerned with the many practical problems which arise in the course of the particular activity concerned and which are not and cannot, be dealt with in a general engineering educational course. The broader background which is necessary if proper advantage is to be taken of the instruction provided is ensured since the holding of a National Certificate, or some equivalent distinction, is a pre-requisite for entering on a course. These specialised courses may be compared, very favourably, with the corresponding graduateship curricula of many American universities.

INSTITUTION EXAMINATIONS

The subject of instrument making and maintenance which figures among the activities of the City and Guilds of London Institute is also dealt with in part-time day and evening classes at the Northampton Polytechnic in St. John-street, London. This institution conducts a four-year course in watch and clockmaking and repairing, but its main activity in this particular connection is concerned with instrument engineering. A six-year course leads up to a Higher National Certificate, and students may extend their attendance over two further years and cover such subjects as industrial administration and metallurgy. Those successfully completing the six-year course are granted exemption from the Associate Membership examination of the Institution of Mechanical Engineers. The course in watch and clockmaking and repairing referred to above is actually that of the National College of Horology and Instrument Technology which is situated at the Northampton Polytechnic. Although the National College of Horology, which was established in 1946, continues its work on watch and clock making, its interests now cover the important and growing field of instrument technology.

WRITING TECHNICAL REPORTS

Among other technical educational institutions in the London area, the Sir John Cass College may be mentioned. This establishment, originally known as a Foundations School, dates from 1710. In its modern form, and under its modern name, it holds courses in physics, mathematics, chemistry and metallurgy and prepares students for the external examinations of the University of London. Two other London educational institutions are offering courses which, although not directly concerned with the scientific training of technologists, are likely to prove of value to any student who attends them. The Borough Polytechnic is providing a course of six lectures on the writing of technical reports. In the early years of his educational course the average student may not be called upon to write a technical report, but in as far as attendance at this course, which is to be held in the evenings, teaches him how to express himself in writing he may find it a considerable help in passing examinations. The other course, held at the Regent Street Polytechnic, deals with the social skills of management. This is intended for industrial executives, rather than students, but those of the latter class who have completed a course in industrial administration would, no doubt, find it of value. The courses outlined here begin in general in the latter weeks of September, or early in October.

The addresses of the institutions referred to in this article are as follow:—

Mid-Essex Technical College and School of Art, Market-road, Chelmsford.
The Technical College, Clifford-street, York.
The Technical College, Lauder-street, West Hartlepool.
The College of Technology, Guildhall-square, Portsmouth.
South East London Technical College, Lewisham-way, London, S.E.4.
City and Guilds of London Institute, 31 Brechin-place, South Kensington, London, S.W.7.
Northampton Polytechnic, St. John-street, London, E.C.1.
National College of Horology and Instrument Technology, St. John-street, London, E.C.1.
Sir John Cass College, Jewry-street, Aldgate, London, E.C.3.
Borough Polytechnic, Borough-road, London, S.E.1.
The Polytechnic, 309 Regent-street, London, W.1.

PROGRESS IN AIR TRANSPORT*

THE TURBO-PROPELLER, THE HELICOPTER, THE JET

By Peter G. Masefield, M.A., F.R.AE.S.†

Given below is the latter half of Mr. Masefield's paper on "Recent Progress in British Air Transport," in which he discusses the potentialities of the short-haul and long-haul propeller-turbine air-liner, the helicopter, and the issue between the large jet aeroplane and the turbo-propeller aeroplane over long ranges. In the earlier part of the paper, not reproduced here, Mr. Masefield surveys the state of air transport in 1955 and examines the breakdown of costs and revenue, from which he draws the conclusion that cost is related to hours flown and to landings made, whereas revenue is related to miles covered; and that currently the lowest operating costs are achieved over sector distances of about 1,500 miles whereas greatest profits are made over distances of about 1,200 miles.

THE TURBO-PROPELLER AEROPLANE

The Vickers Viscount—the world's first propeller-turbine airliner—went into regular commercial service with B.E.A. on April 19, 1953. In the 2¼ years since then B.E.A.'s Viscounts have flown some 12½ million aircraft miles, carried some 630,000 passengers, earned approximately £12,000,000 of revenue and have made a profit of £1,200,000. At the same time, orders for more than 200 Viscounts have been secured from airlines all over the world.

The turbo-propeller engines have four important qualities. They are basically simple—no carburettors, no magnetos, no plugs, no reciprocating parts. They weigh less than half a piston engine of similar power. They originate very little vibration. And, although they have at present a fairly high rate of fuel consumption, they run on ordinary household kerosine, or paraffin, which is both cheaper and less volatile than high octane gasoline and has a higher calorific value.

Operations with the Viscount B.701A in B.E.A. service have shown that it has the following characteristics:

	Sector distance		
	At 200 miles	At 600 miles	At 1,000 miles
Maximum payload	11,808 lb.	11,808 lb.	11,450 lb.
Block speed	150 m.p.h.	245 m.p.h.	270 m.p.h.
Time for distance	1·33 hrs.	2·45 hrs.	3·70 hrs.
Cost per aircraft mile	18·6*s.*	10·5*s.*	8·86*s.*
Cost per seat mile	4·75*d.*	2·69*d.*	2·26*d.*
Number of passengers required to break even on total costs	28·4	18·3	16·6
Total revenue per annum earned to each aircraft at 65 per cent. load factor	£285,000	£464,000	£516,000
Total cost per annum incurred by each aircraft	£265,000	£276,000	£280,000
Net profitability per annum by each aircraft	£20,000	£188,000	£236,000

These figures are still improving and set a standard for modern short and medium-haul air transport operation.

In the longer-range types the turbo-propeller also gives promise of outstanding possibilities. The Bristol Britannia is designed as a long-range aeroplane for Commonwealth and North Atlantic services. Over short ranges its economics are, naturally, not so good as the Viscount, but it is the most formidable long-range airliner which has yet flown, because it combines a relatively high speed with large payload and good economics in a spacious and quiet fuselage.

* Paper read before Section G of the British Association at Bristol on Tuesday, September 6, 1955. Abridged.

† Chief executive, British European Airways.

The most economic sector distance for the longer-range version of the Britannia is some 3,750 statute miles. Over this distance it can achieve a minimum operating cost of 10*d.* a ton mile—which compares with the Viscount's minimum of 12*d.* a ton mile achieved at 1,100 miles. At the 1,100-mile distance the Viscount has a lower specific cost than the Britannia.

THE HELICOPTER

At the other end of the scale on very short ranges a quite different situation prevails. The fixed-wing aeroplane has a high cost and shows little time saving at distances short of about 180 miles. In this realm the helicopter gives promise of becoming an excellent solution on a journey-time basis, because it can fly directly between city centres. Unfortunately from the economic viewpoint there is at present no more expensive means of progression.

The reason for this is that the helicopter is still small, complex and slow. It cannot carry enough payload to cover the basic elements in cost which vary little with size—crew pay, radio installations, etc. Its complexity and its slowness mean that its maintenance costs are relatively high for each revenue mile flown. For the types of helicopter at present available, over a sector distance of 50 miles a fare of at least 30*d.* a mile would have to be charged to meet costs—a figure which could not be charged commercially because practically no traffic would be prepared to pay it.

On the other hand, a helicopter cruising at 120 m.p.h. would be able to offer a significantly faster time than any commercial fixed wing aeroplane of to-day, up to distances of about 400 miles between city centres, because the helicopter is not handicapped by the slow bus journey which exists between most cities and their airports.

Indeed, a fixed-wing aeroplane would have to travel at about 3,400 m.p.h. between airports 200 miles apart if the total journey time of its passengers between city centres were to be no longer than that of the passengers flying directly in a 120-m.p.h. helicopter.

The problems which remain to be solved before the helicopter can become a satisfactory commercial vehicle are (1) size: not less than 50 seats, to achieve economy; (2) speed: not less than 150 m.p.h., to achieve punctuality in all weathers; (3) reliability: not less than two engines, and ability to maintain height with one out of action; and (4) noise: not more than 80 decibels at 100 ft. at take off and landing, for city acceptability. Ten years are likely to pass before these objectives are achieved. The helicopter, even then, will have to be confined to routes where the traffic will support a reasonable frequency with good load factors, in vehicles with not less than 50 passenger seats. That means that the helicopter is likely to become—by 1965—a convenient means of transport, at fairly high fares, between large centres up to 200 miles apart. Beyond this distance the fixed wing aeroplane will continue to be cheaper and, by then, faster.

In the long-term future, however, we must not ignore the possibilities of vertical take-off with fixed wing aircraft—although, for a long time to come, the noise factor will probably rule it out of city centres.

JET VERSUS TURBO-PROPELLER

The big issue in the next few years is the battle which is likely to develop over long ranges between the very large jet aeroplane and the big turbo-propeller aeroplane.

Over long ranges—such as the North Atlantic operation—an extremely interesting position is developing with, on the one hand, the British Bristol Britannia, representative of the long-haul turbo-propeller and, on the other, the Douglas DC-8 and the Boeing 707, representative of the larger jets.

Both these latter aircraft are very big indeed, accommodating 125 or more passengers in their tourist configurations, compared with the maximum of 96 passengers in the biggest version of the Britannia at present being produced. Neither of the American jets is likely to be available in non-stop North Atlantic form, however, for about six years to come. First deliveries of the DC-8 in a shorter-range form, for U.S. domestic operations, are promised for 1959.

The Britannia will, we may hope, be on B.O.A.C. North Atlantic services within the next three years. It will thus have a substantial lead in time, experience and reliability over the big United States jets.

A comparison of the relative characteristics of these aircraft outlines this most fundamental technical economic problem of the moment. The figures can be set out as follow:—

Engines	Britannia 300LR		Douglas DC-8
	Proteus 755 (Turbo-prop)	BE.25 (Turbo-prop)	J.57 (Jet)
Approximate date for North Atlantic service	1958	1962	1962
Maximum tourist passenger seating	96	96	125
Maximum payload for London-New York	28,000 lb.	28,000 lb.	32,400 lb.
Cruising speed (m.p.h.)	360	420	550
Maximum gross weight	170,000 lb.	170,000 lb.	257,000 lb.
Maximum fuel load	68,000 lb.	68,000 lb.	120,500 lb.
Maximum sector distance with full fuel and reserves	5,100 mls.	6,100 mls.	4,800 mls.
Relative cost per ton-mile	100	77	82
Representative journey time London-New York (Vs. headwinds)	12 hrs.	10 hrs.	8 hrs.

From these figures—which at this stage must be approximate—we can see that whereas the big jet has the advantage in speed the big turbo-propeller is likely to be usefully cheaper to operate.

The Proteus 755 Britannia will be substantially ahead of any contemporary piston-engine aircraft in comfort and economy with at least equal speed. The developed Britannia with the new Bristol BE.25 engines, 60 of which engines are on order by B.O.A.C., seems likely to show a 60 m.p.h. improvement in speed and a 23 per cent. improvement in economy, compared with the Britannia 300LR with Proteus 755 engines. If the Britannia were given a bigger body its economy could be improved a good deal more, without any significant change in speed.

Against this will emerge the new, large, United States jets—represented by the Douglas DC-8 (125 passengers), the Boeing 707 (130 passengers), and also by a new Convair design of about equal size. Even with their increased payload they are not likely to get down to the same low cost level as the developed Britannia. Indeed, preliminary estimates made, on the most objective basis, suggest that the 96-passenger BE.25 Britannia will be some 5 per cent. cheaper per ton mile to operate, compared with the 125-passenger DC-8—which means that, for equal sizes of payload, the turbo-propellers would be about 20 per cent. cheaper per seat mile—a significant difference. So we come back to the fundamental question. Assuming equal size of aircraft—will the turbo-propeller be competitive with the jet—the turbo-propeller taking three hours longer for the London-New York non-stop journey at a return fare which might be £40 cheaper on tourist fares?

My belief is that there will be a place for both types of aircraft. The big jet will take the first-class traffic at fares quite substantially higher than the tourist versions of the turbo-propeller aircraft. The essential thing is that both types of aircraft should fly non-stop in all normal weathers. The turbo-propeller is likely

to achieve a high regularity of non-stop operations on the North Atlantic a good deal sooner than the jet. The struggle between the rival forms of turbine power-plant will be settled in the cold, hard, light of airline competition and economics—with passenger's pockets and preference playing a dominant part in determining the technical answer.

At the present time, air transport is operating profitably and expanding steadily—still powered predominately with piston engines and meeting increased traffic demands with still more orders for developed versions of existing four-engine pressurised piston aircraft, such as the Douglas DC-7c and the Lockheed 1649.

The turbo-propeller aeroplane is, however, on the way in on a substantial scale—with the Viscount already showing the potentialities of this new power-plant in extensive service. Closely behind it comes the long-range Britannia, the medium-range Viscount-Major and, on the other side of the Atlantic, the Lockheed Electra. During the next eight years more than a thousand of these three types of aircraft are likely to be sold in World markets. And, during this time, orders for new piston-powered transport aircraft will begin to fade.

The big jets now seem likely to come in, extensively, first on United States trans-Continental services—with the de Havilland Comet 4 making its mark on Commonwealth routes, we may hope, still considerably earlier.

Further ahead, two major developments are already looming—supersonic passenger transports and vertical take-off. Both of these technological advances can alter the whole pattern of air transport—and of World trade—as we know it to-day. When the time comes—as come it will—that the trans-Atlantic non-stop "Hypersonicia" pops silently and vertically out of the "spout" of its underground terminal in the centre of London and alights two hours later in its counterpart in New York—then the world will be shrunk to one tenth of its present size and the possibilities of trade and economic prosperity immensely increased.

* * *

CONTRACTS

Diesel Rail Cars. A contract has been placed by the British Transport Commission with D. WICKHAM AND CO. LTD., Ware, Hertfordshire, for five 150-h.p. power cars and five trailer cars for multiple-unit Diesel trains. The power units are to be supplied by BRITISH UNITED TRACTION CO. LTD. These cars are part of the modernisation programme and will be used on the Eastern Region.

Diesel Shunting Locomotives. W. G. BAGNALL LTD., Stafford, have received a contract from the New Zealand Government Railways for seven 0-4-0 Diesel-mechanical shunting locomotives of 150 h.p. Two are to have 6L3 engines made by L. GARDNER AND SONS LTD., Patricroft, Manchester, and the remainder M6 engines made by J. AND H. MCLAREN LTD., Leeds 10. A FLUIDRIVE hydraulic coupling will be used in conjunction with a gear-box manufactured by SELF-CHANGING GEARS LTD., Lythalls-lane, Coventry.

Materials Handling Equipment. A contract for the materials handling equipment for a blast furnace in the Ravenscraig project at Motherwell, has been placed by Colvilles Ltd., Glasgow, with RICHARD SUTCLIFFE LTD., Horbury, Wakefield, through ASHMORE, BENSON, PEASE AND CO., Stockton-on-Tees. The equipment includes 14 belt conveyors together with screens, feeders, bunkers and structural steelwork for handling ore, limestone, coke, breeze and flue dust.

Turbo-Alternators for Geo-Thermal Power Station. THE BRITISH THOMSON-HOUSTON CO. LTD., Rugby, have received an order from the New Zealand Government (on behalf of the New Zealand Ministry of Works) for five steam turbo-alternator sets for the No. 1 Wairakei Geo-Thermal power station, which is part of a heavy-water project. Two of the sets will be driven by steam from the thermal boreholes at 180 lb. per sq. in. gauge and 380 deg. F. and will exhaust to the heavy-water plant at 50 lb. per sq. in. The remaining three will receive steam from the plant at 15 lb. per sq. in. abs. and exhaust into jet condensers supplied by the MIRRLEES WATSON CO. LTD., Glasgow. Consultants for the contract, which is valued at £750,000, are MERZ AND MCLELLAN, 32 Victoria-street, London, S.W.1.

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PERSONAL

Three new appointments are being made by the British Broadcasting Corporation. MR. H. F. BOWDEN, the present assistant engineer, is to succeed MR. S. A. WILLIAMS, M.B.E. (who has retired) as engineer-in-charge of the short-wave station at Skelton, Cumberland. MR. J. J. ALLEN, of the Planning and Installation department of the television section becomes engineer-in-charge of the television station at Les Platons, Jersey, and MR. W. BALFOUR becomes engineer-in-charge of the Meldrum, Aberdeenshire, television station, in addition to his present appointments at Aberdeen and Redmoss.

MR. C. E. H. VERITY, O.B.E., M.I.C.E., M.I.Mech.E., M.I.E.E., is relinquishing his post as Deputy Chief Engineer (Generating Station Construction), Central Electricity Authority, to take up an appointment on the board of Foster Wheeler, Ltd., 3 Ixworth-place, London, S.W.3.

The Council of the British Institution of Radio Engineers have awarded the Clerk Maxwell Premium (their premier award) to MR. F. N. H. ROBINSON, M.A., Research Fellow at the Clarendon Laboratory, Oxford, for his paper entitled "Microwave Shot Noise in Electron Beams and the Minimum Noise Factor of Travelling Wave Tubes and Klystrons."

MR. J. JEFFERSON, technical manager of the marine division of Steels Engineering Installations Ltd., Sunderland, and MR. W. GRAHAM, manager of the Birmingham branch, have been made directors of the company.

Ericsson Telephones Ltd., Beeston, Nottinghamshire, announce that MR. R. G. HOSKINS has been appointed superintendent-in-charge of the firm's factory at Southwick, Sunderland.

The following changes are announced by the Ministry of Supply: MR. E. T. JONES, C.B., O.B.E., is to become Director-General of Technical Development (Air) in succession to MR. G. W. H. GARDNER, C.B., C.B.E., who takes over the post of Director of the Royal Aircraft Establishment, Farnborough, on November 1. Mr. Jones will be succeeded as Principal Director of Scientific Research (Air) by DR. W. CAWOOD, C.B.E.

The Institute of General Managers, 86 Eccleston-square, London, S.W.1, announce that the following have been appointed to the Council: SIR CHARLES CUNNINGHAM, C.S.I., and MR. S. COLLIER, M.C. Both are foundation Fellows of the Institute.

The Sheepbridge Group announce that MR. J. W. LENNOX has been appointed general manager of Sheepbridge Alloy Castings Ltd., Sutton-in-Ashfield, Nottinghamshire, in addition to his present posts of director and general manager of Sintered Products Ltd.; and that MR. R. DUTTON-FORSHAW has been appointed to the board of Sheepbridge Engineering Ltd., Chesterfield.

MR. H. V. POTTER has announced his resignation from the post of managing director of Bakelite Ltd., 12 Grosvenor-gardens, London, S.W.1, as from October 31. He will continue as chairman of the board and will be succeeded by MR. G. W. HODDS. In addition, MR. F. J. ROBINSON is relinquishing his position as deputy managing director.

Ferodo Ltd., Chapel-en-le-Frith, announce some changes in their board of directors. MR. WILLIAM SMITH will relinquish his duties as managing director at the end of September and retires from business at the end of the year. MR. G. S. SUTCLIFFE will become managing director and MR. E. R. POCHIN will become Home Sales director. MR. M. H. GOOD will follow Mr. Pochin as Home Sales manager and DR. N. CARPENTER will become Technical Sales manager.

The retirement is announced of MR. F. C. PYMAN managing director of William Gray and Co. Ltd., West Hartlepool. MR. STEPHEN FURNESS will become deputy chairman and will be joint managing director with MR. W. T. GRAY. Other new directors are MR. KENNETH DOUGLAS, general manager of the shipyard; MR. S. H. DUNLOP, general manager of the engine works; and MR. J. L. STEWARD, the company secretary.

The award of the Elliott Cresson medal, presented annually by the Franklin Institute of Philadelphia, has this year been made to DR. F. B. BOWDEN of the Department of Physical Chemistry, Cambridge, for his experimental work generally and in particular for that concerning the sliding of one metal over another.

The British Iron and Steel Research Association, 11 Park-lane, London, W.1, report that MR. R. H. COLLCUTT has been appointed Head of the Operational Research section in succession to MR. R. T. EDDISON who resigned last June.

MR. A. J. NICHOLSON has left the Department of Agricultural Engineering, King's College, Newcastle-upon-Tyne, to take up an appointment in the research department of the British United Shoe Machinery Co. Ltd., Leicester.

International Combustion Ltd., 19 Woburn-place, London, W.C.1, announce that MR. VERNON YOUNG, F.C.I.S., has been appointed chairman of the company and that MR. WALTER GRAINGER, M.Inst.F., and MR. JOHN MAYER, B.Sc., A.M.I.Mech.E., will be joint managing directors.

SIR SUMMERS HUNTER, who has retired from the position of managing director of Richardsons, Westgarth and Co. Ltd., has joined the board of directors of Vent-Axia Ltd., 9 Victoria-street, London, S.W.1.

MR. A. P. HARVEY, A.M.I.E.E., has been appointed chief engineer of the switchgear division of the Brush Electrical Engineering Co. Ltd., Loughborough, in succession to MR. V. W. LOWE.

MR. H. A. SARGEAUNT, O.B.E., B.A., at present scientific adviser to the Army Council, has been appointed assistant to DR. H. P. ROBERTSON of the United States, who is the scientific adviser to General Gruenther, the supreme allied commander, Europe.

SIR PERCY H. MILLS, the first President of the Institute of Industrial Supervisors, 24 Albert-street, Birmingham, 4, has been awarded the Edward O. Seits Memorial Award for International Management, presented by the National Association of Foremen of America.

MR. C. H. STOCKS, A.F.C., M.Sc., principal surveyor to Lloyd's Register of Shipping, 71 Fenchurch-street, London, E.C.3, for the Bristol Channel ports, is to retire from the service of the Society on September 30, after 36 years of service. MR. J. WORMALD, B.Sc., a senior ship and engineer surveyor at Cardiff, has been appointed to succeed Mr. Stocks as principal surveyor for the Bristol Channel ports.

MR. FRED KENDRICK has been appointed a director of the Sheffield Forge and Rolling Mills Co., Ltd., Millsands, Sheffield, one of the companies of the Darwins Group.

MR. C. W. CLARK, A.R.Ae.S., M.I.P.E., managing director of Smart and Brown Machine Tools Ltd., of Biggleswade, Bedfordshire, and of 25 Manchester-square, London, W.1, has been appointed managing director of Modern Machine Tools Ltd., of Coventry. MR. P. E. VERRALL, A.M.I.P.E., has also joined the board of Modern Machine Tools Ltd., as a director.

MR. MARCUS E. D. TAYLOR, P.Eng., A.M.I.Mech.E., has been appointed chief engineer of the Naval Engineering Design Investigation Team, Montreal, Canada.

MR. H. C. MAGUIRE, hitherto depot manager, Liverpool, of the Marconi International Marine Communication Co. Ltd., Chelmsford, Essex, has been appointed to the new post of export sales manager, at Marconi House, Chelmsford. The appointment has been created in view of the increasing volume of the firm's overseas business. Mr. Maguire is being succeeded as depot manager at Liverpool by MR. J. MITCHELL, who has been assistant depot manager there since 1952.

* * *

COMMERCIAL

An agreement has been reached whereby TAYLOR BROS. AND CO. LTD., Trafford Park Steel Works, Manchester, 17, are to supply technical assistance to the AMERICAN ROLLING MILLS CORP. regarding the installation of a railway-wheel manufacturing plant. It is understood that the new plant will be based on the design and layout of that at Trafford Park and that there will be an exchange of engineers between the two companies. The plant was described in ENGINEERING, vol. 174, page 713 (1952). (Editorial comment in Weekly Survey.)

The new address of the office of the UNITED KINGDOM TRADE COMMISSIONER in Toronto, Canada, is now 119 Adelaide-street West, Toronto. (Telegraphic address: Toroncom Toronto; telephone: EMpire 2-1223.)

Additional facilities for their parts service have now been provided by the British CATERPILLAR TRACTOR CO. LTD., at Desford, Leicestershire.

Letters to the Editor

THICK-WALLED CYLINDERS UNDER INTERNAL PRESSURE

A Solution from America

SIR, Your journals in their travels through the different departments in our organisation, often meet with prolonged hold-ups at one desk or another, and the following comments are therefore rather late, as the original article was published early this year, although the ensuing discussion lasted for some time and is probably fresh in the minds of many readers.

I refer to the article on "The Ultimate Strength of Thick-Walled Cylinders Subjected to Internal Pressure," by B. Crossland and J. A. Bones (ENGINEERING, vol. 179, pages 80 and 114) and the debated possibility of expressing the bursting strength by a simple formula. As engineers and fabricators of high-pressure equipment, we in this company have long been much interested in this subject and have attempted a solution of the problem of ultimate strength, by an approach similar to, yet in many ways distinctly different from that of Manning (see references to above article).

On the basis of the octahedral shear-strain theory, the basic equation is:

$$p = \frac{2}{\sqrt{3}} \int \frac{S}{r}\, dr.$$

S can be taken as the equivalent tensile stress, which will produce the actual shear stress in a simple tensile test, and can therefore be taken from a tensile stress-strain diagram. All workable theories are based on the assumption that the cross-sectional area of the cylinder will remain unchanged at all pressures. This can be expressed as ϵr^2 = constant. When the basic equation is graphically integrated and plotted, with abscissae r on a logarithmic scale, it shows a curve, which is almost a straight line for values of p in the plastic or strain-hardening zone, even for materials with a pronounced curvature in the tensile stress-strain diagram. Integrating a number of widely different stress-strain diagrams revealed furthermore, that the p-curve starts a downward slope when reaching a value of r, corresponding to the ultimate strain ϵ_u residing at this r. If r is taken as the inside radius, then, according to Manning's theory of an unstable condition, this is the condition that will cause failure. When K is the wall ratio in the unstressed state, then, at the point of failure, the ratio for the stressed state is:

$$K' = \frac{K^2 + \epsilon_u}{K(1 + \epsilon_u)}.$$

It was thought that a formula for the bursting pressure should have the form:

$$p = \frac{2}{\sqrt{3}} S_u \log_e K'.$$

This formula, when compared with the integrated p-curve, showed too high values for p for large values of K′. The next attempt was:

$$p = \frac{2}{\sqrt{3}} S_{av} \log_e K'$$

where $S_{av} = A/(\epsilon_u - \epsilon_o)$ equals the mean ordinate of the area A under the stress-strain diagram between ϵ_u and ϵ_o (ϵ_o = strain at outside wall). This formula shows similar deviations as the previous one, although to a smaller degree.

The formula finally selected was:

$$p = \frac{2}{\sqrt{3}} \frac{S_u + S_o}{2} \log_e K'$$

where S_o = stress at outside wall strain ϵ_o, and

$$\epsilon_o = \frac{\epsilon_u}{(K')^2}$$

The values of p found from this formula are amazingly close to those obtained by the integrated p-curve. Even for a steel like A.S.T.M. A-212, which shows a sharp increase in tensile stress of over 50 per cent. immediately following the yield point, the formula shows practically no deviation, even when ϵ_o approaches the yield strain. If there is any theoretical foundation for this, it has eluded your correspondent.

Yours very truly,
S. M. JORGENSEN.

Foster Wheeler Corporation,
New York, N.Y.
September 7, 1955.

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FLUID SEAL FOR RECIPROCATING SHAFTS

SIR, With reference to Mr. R. N. Johnson's letter in your issue of September 2, regarding the article on the "Hallprene" patent fluid seal, we feel that he will find the points raised by him were dealt with in a letter over the signature of Mr. T. F. Watson which appeared in your columns on March 11, 1955 (page 293).

Yours faithfully,
J. S. JARVIS.

Hall & Hall, Ltd.,
Hampton,
Middlesex.
September 8, 1955.

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Obituary

MR. ROBERT BLACKBURN

Aviation Pioneer

We record with regret the death of one of the British pioneers of aviation, Mr. R. Blackburn, O.B.E., M.I.Mech.E., A.M.I.C.E., Hon. F.R.Ae.S., which occurred on Saturday, September 10.

Robert Blackburn was born in Leeds on March 26, 1885, and was educated at Leeds Modern School. He studied engineering at Leeds University and, subsequently, in Belgium and France. In 1908 he saw the Wright brothers give their first demonstration in Paris, and it was this that determined his future career. The following year he designed, constructed and flew his first aeroplane at Saltburn Sands, North Yorkshire. In 1911 he designed a steel military monoplane, one of the first successful all-metal aircraft. For 18 months he ran a flying school at Hendon.

In 1912, Mr. Blackburn started a private company for constructing aircraft, and the aircraft that he built in the first year of his new company, the Blackburn 1912 monoplane, is still in excellent condition and has been flown in public on several occasions since the second World War.

In 1915 his private company was turned into a public company, the Blackburn Aeroplane and Motor Company, Limited, and his predominant interest in seaplanes and naval aircraft began to emerge. At the end of the first World War he received the O.B.E. in recognition of his services, and in 1918 he was made a Fellow of the Royal Aeronautical Society.

He formed, in 1919, North Sea Aerial and General Transport Limited. He was instrumental in starting many factories abroad, and in March, 1927, the Greek government conferred upon him the Golden Cross of the Order of the Redeemer in recognition of services to the Greek Naval Aircraft Factory near Athens.

In 1936, he became chairman and managing director of Blackburn Aircraft Limited, merging several interests, including the Cirrus Hermes Engineering Company. Among the aircraft built by this company was the Skua, the first monoplane dive bomber produced for the Fleet Air Arm, and the Botha, a torpedo bomber. After the war the company merged with General Aircraft Limited, to become Blackburn and General Aircraft Limited, with Robert Blackburn as chairman. The principal accomplishments of the re-formed company have been the production of the Blackburn Beverley military freighter; and the construction under licence of the French Turboméca range of small gas turbines for both aeroplanes and industry.

From 1945 to 1946 Mr. Blackburn was vice-president of the Society of British Aircraft Constructors, and he served on the society's management committee from 1950 to 1952.

BRITISH ASSOCIATION MEETING

SPACE FLIGHT; SCIENTIFIC DESIGN OF LOCOMOTIVES

In last week's report of the Bristol meeting of the British Association we referred to Mr. M. W. Rosen's paper on "The Influence of Space Flight on Engineering and Science." The paper is published elsewhere in this issue and the discussion is reported below.

To a speaker who inquired whether photographs taken from the rockets showed the curvature of the earth, Mr. Rosen replied that some of those included in the film did so. One (it is reproduced in Fig. 3, on page 373) taken from a height of about 140 miles showed approximately 1,000 miles of horizon and distinctly illustrated the earth's curvature. Dr. H. L. Davies asked what was the present stage in the technical development of the escape velocity. To this question the author replied that two velocities were concerned: the satellite velocity of about 25,000 ft. per second and the escape velocity of approximately 36,000 ft. per second. A single-stage Viking rocket had reached a velocity of 6,300 ft. per second, so that it would not be possible to attain the required velocity with a single-stage rocket, but if the figure for a single-stage rocket could be increased to 9,000 ft. per second, which he thought was conceivable, the escape velocity could be reached with a three-stage rocket. A two-stage rocket had already been launched and had attained a velocity of 9,000 ft. per second and had established the world height record of 250 miles.

After a few additional questions had been asked and answered, the Chairman proposed a vote of thanks to Mr. Rosen for his pioneering paper which, he said, gave a good idea of the progress made and the cost this progress entailed. The vote of thanks was accorded with acclamation and the session terminated.

When the meeting was resumed after the interval on Friday morning the chair was taken by Dr. S. G. Hooker, a vice-President of the Section, who called on Mr. J. S. Tritton to give a paper entitled "The Scientific Development of Modern Locomotive Designs," of which he was joint author with Mr. J. C. C. Paterson. After explaining that Mr. Paterson was unable to be present, as he was recovering from an operation, Mr. Tritton gave a summary of the paper which is reprinted in this issue of ENGINEERING. The paper reviewed the scientific methods adopted in the development of steam, Diesel and gas-turbine locomotives.

At its conclusion, the Chairman invited discussion and the first speaker, Mr. L. H. Pretty, inquired on what lines research into the reduction of atmospheric pollution by locomotives was being conducted. Mr. Tritton replied that the problem had been taken up very actively by the British Transport Commission's research department at Derby, not only because atmospheric pollution had been the subject of serious comment by the public but also because it involved the railways in very high maintenance costs. Its

reduction was one of the advantages to be derived from electrification and from the use of Diesel and gas-turbine propulsion.

Mr. H. Young inquired what were the prospects of hydraulic transmission becoming more general on large locomotives. In reply, Mr. Tritton said that, in Germany, two systems had been studied and one of these could be very effective. There did not appear to be much difference between the efficiencies of the hydraulic and electrical systems and he believed that his electrical friends would claim that their system was quite as reliable as the hydraulic system. Strong claims, however, were being put forward for the latter that it had practically no maintenance costs, so that once the difficulty of heat dissipation under heavy loads had been overcome it was not necessary to touch the transmission from one year's end to another. The information was, however, secondhand to him and he would not care to make it an official statement.

Wing Commander T. R. Cave-Browne-Cave asked why the coal-burning gas turbine should be considered for locomotives and Mr. Tritton replied that the Ministry of Fuel and Power had decided to investigate its possibilities, possibly because coal was an indigenous fuel and more particularly, perhaps, because the public appreciated that a lot of our valuable coal resources were being consumed very wastefully at an efficiency of the order of 6 per cent. in the old steam locomotive. If a coal-burning gas-turbine locomotive could be developed which, for the same output, would consume only half the amount of coal used in a steam locomotive there would be a useful economy in the use of the natural product.

The chairman then remarked that it appeared to him that the advantage of the Diesel-electric locomotive was due more to the electrical transmission than to the engine. The gas-turbine locomotive, he thought, seemed to be following very closely the developments which had taken place in connection with aircraft. He suggested that by the use of two compressors and increasing the compression ratio, the thermal efficiency could be improved; as it would also be by the use of a heat exchanger. By dividing the compressor, a compression ratio of 6 to 1 could easily be employed instead of the more usual ratio of 3 to 1. Whereas the locomotive was operating with an air temperature of 1,300 deg. F., the working temperature was of the order of 900 deg. C. Aircraft engines, however, were not required to operate for so many hours without overhaul as was the locomotive engine. In aircraft, moreover, they were working on a system of cooling the blades by forcing air through them. He felt that on such lines there was a great future for the gas-turbine locomotive.

Replying, Mr. Tritton assured Dr. Hooker that locomotive engineers had these matters very much in mind. The permutations and combinations of lay-out were, however, almost innumerable. Regarding the use of a heat exchanger, however, he pointed out that space and weight were greatly restricted in a locomotive; a heat exchanger, moreover, was difficult to look after in daily operation and it was found that the increased efficiency resulting from its use did not compensate for the disadvantages in operation and maintenance.

The last speaker in the discussion, Mr. J. W. Voelcker, said he thought that gas-turbine locomotives would be used in this country essentially for main-line working. To this comment Mr. Tritton replied that the gas turbine had the advantage of giving a high starting torque which the Diesel engine had not. He believed it was safe to say that the gas turbine gave a stalled torque of 2¼ to 2½ times the running torque and if the turbine could be coupled directly to the wheels of the locomotive, without electrical or hydraulic transmission, there would be important gains from both weight reduction and higher efficiency.

The chairman then thanked the authors of the paper on behalf of the members and the session terminated.

To be continued

BOOKS RECEIVED

Some of the books noticed here are selected for extended review in ENGINEERING.

A Handbook of Hard Metals. By W. DAWIHL. Published for the Department of Scientific and Industrial Research by *H.M. Stationery Office, Kingsway, London, W.C.2.* (25*s.*)

This volume of 160 pages, constitutes a British translation of the major portion of the *Handbuch der Hartmetalle*, by Dr. W. Dawihl, now a reader in metallurgy at the Illingen University, Saar, and an authority on sintered-metal techniques. The *Handbook* deals with three principal classes of hard metals, namely, sintered alloys of hard carbides to which small amounts of metals have been added; alloys having a tungsten-carbide base, formed by melting and casting; and hard-facing alloys applied by gas or electrical welding methods on to a base material. Three firms shared the task of translation. They were: Hard Metals Tools Ltd., Coventry; the Metropolitan-Vickers Electrical Co., Ltd., Manchester, and Murex Ltd., Rainham.

The Suppressed Frame System of Telerecording. By C. B. B. WOOD, E. R. ROUT, A. V. LORD and R. F. VIGURS. B.B.C. Engineering Monographs No. 1. *B.B.C. Publications, 35 Marylebone High-street, London, W.1.* (5*s.*)

This is the first of a series of monographs which the British Broadcasting Corporation has decided to publish on technical developments related to sound and television broadcasting. It summarises the fundamental and practical aspects of a suppressed-frame 35-mm. telerecording channel, which was designed by the Engineering Research Department primarily to provide additional facilities in connection with the Coronation. In view of the comparatively short time that was available, tests were made to determine the picture quality which could be obtained with a high-grade television monitor and a commercial cine-camera. The results indicated that the construction of an apparatus of this type was justifiable.

Forest Products Research, 1954. Published for the Department of Scientific and Industrial Research by *H.M. Stationery Office, Kingsway, London, W.C.2.* (3*s.* 6*d.*)

This report of the Forest Products Research Board contains a general description of the Board's work, followed by the report of the Director of Forest Products Research, divided into the following general headings: seasoning, timber mechanics, woodworking, composite wood, wood preservation, mycology, entomology, chemistry, physics, and external relations of the Board.

Civil Engineering Design: Notes and Sketches. By T. W. BARBER. Fourth edition revised and enlarged by ROLT HAMMOND. *The Technical Press, Limited, 1 Justice-walk, Lawrence-street, London, S.W.3.* (25*s.*)

According to the preface, the object of this book is " to present in one handy volume a large number of sketches of representative machines, materials and methods employed in civil engineering." Classified under headings such as foundations, structural steelwork, etc., each sketch is accompanied by a brief description. Only the basic lines are shown, much detail having been eliminated for clarity. In this fourth edition a bibliography has been added covering books (not the technical Press nor Institution papers) for the period since 1945. The book makes a convenient handbook for students leaving technical schools.

A.S.T.M. Standards in Building Codes. *American Society for Testing Materials, 1916 Race-street, Philadelphia 3, Pennsylvania, U.S.A.* (6 dols.)

This publication brings together, for the first time, a complete set of A.S.T.M. specifications, methods of test, and definitions of materials included by reference in the major building codes of the United States and Canada. It is designed for the use of building code authorities, and it is proposed to compile needed supplements to this publication each year. The standards in this compilation cover the full range of construction materials including structural and reinforcing steel; steel, cast-iron and copper pipe; building units; bituminous roofing; cement; gypsum; and ready-mixed concrete.

Regulations for the Electrical Equipment of Buildings. Thirteenth edition. *The Institution of Electrical Engineers, Savoy-place, London, W.C.2.* (6*s.*)

This edition of a publication which first appeared in 1882 is in two parts. The first is based on those requirements in an electrical installation which, if not complied with, would enable the supply authority either to refuse to connect or to disconnect. The second part sets out the methods and practices by which the requirements of Part I can be met, although these do not necessarily represent the only means of compliance. As with all previous editions the thirteenth is intended to ensure safety from fire and shock in the installations to which it relates. It embraces a number of suggestions of interested bodies and takes into account proved advances in installation techniques. It embodies several supplements to the twelfth edition and its publication will result in the withdrawal of certain temporary regulations.

Protective Coatings for Metals. By R. M. BURNS and W. W. BRADLEY. Second edition. *Reinhold Publishing Corporation, 430 Park-avenue, New York 22, N.Y., U.S.A.* (12 dols.); and *Chapman and Hall, Limited, 37 Essex-street, London, W.C.2.* (96*s.*)

The previous edition of this work, which constitutes No. 129 in the American Chemical Society's series of chemical monographs, was published in 1939. The present edition has been enlarged and almost entirely rewritten and aims at making available recent information on the composition, properties and performance of both metallic and organic coatings. Attention is also devoted to such subjects as the preparation of surfaces to receive coatings, methods of testing metallic coatings, and corrosion inhibitors. The object of the book is to meet the needs of engineers, metallurgists and chemists who are concerned with the technology of corrosion control in all its many forms.

Vibration Problems in Engineering. By S. TIMOSHENKO. Third edition in collaboration with D. H. YOUNG. *D. Van Nostrand Company, Incorporated, 250 Fourth-avenue, New York 3, N.Y., U.S.A.* (8.75 dols.); and *Macmillan and Company, Limited, St. Martin's-street, London, W.C.2.* (65*s.*). (Reviewed on page 329, in the issue of September 9).

Introductory Applied Physics. By NORMAN C. HARRIS and EDWIN M. HEMMERLING. *McGraw-Hill Book Company, Incorporated, 330 West 42nd-street, New York 36, N.Y., U.S.A.* (6.75 dols.); and *McGraw-Hill Publishing Company, Limited, 95 Farringdon-street, London, E.C.4.* (50*s.* 6*d.*) (Reviewed on page 329, in the issue of September 9.)

Électrotechnique Générale. Aide-Mémoire Dunod. By M. DENIS-PAPIN. Fourth edition. *Dunod, 92 Rue Bonaparte, Paris 6e.* (480 francs.)

This book is one of a series published under the description of *Aide-Mémoires*. It covers electrotechnology in general and was first published in 1947. The present fourth edition has been carefully corrected and includes some additions of recent conception to bring the work up to date. It is intended for advanced scientific and technical students and students of higher and specialised mathematics as well as electrical engineers, physicists and technicians. Without prejudice to its reference value, the subjects are condensed to the proportions of a handbook divided into sections on:—electrostatics; general information on direct current; magnetism and electro-magnetism; direct-current dynamos and motors; general information on alternating current; testing; measurement units; and wiring diagrams. The text is provided with appropriate diagrams and formulae and there is a supplement of usual tables and formulae.

Elektrische Maschinen. Vol. IV : Die Induktionsmaschinen. By RUDOLF RICHTER. Second edition. *Verlag Birkhäuser, Basel, Switzerland.* (36.40 Swiss francs.)

This volume on induction machines is the fourth in a series on electric machines and is in its second edition. Operation and design calculations are included thus making it a reference work for electrical engineers and advanced students desiring to go more deeply into the subject of this type of motor. The general principles, excluding the effect of harmonic vibration, are first dealt with consideration being given to self-exciting, single-phase and the numerous surface action motors. The behaviour of machines under the effect of harmonic vibration is investigated. Sections on the various methods of starting, braking and speed control are mainly directed to the practical engineer who has to design equipment, and to the operating engineer. Formulae are provided for calculating the additional iron and winding losses and a special section is devoted to experimental investigations. The final section on design, includes a comprehensive example of calculations. There are some 270 diagrams, an explanation of symbols and an alphabetical subject index. Recent progress and changes are introduced at the beginning as supplements, arranged according to the relative section to which they belong.

Book Reviews

WHERE WEST IS MEETING EAST

Science and Civilisation in China. Vol. I: Introductory Orientations. By JOSEPH NEEDHAM, F.R.S., with the research assistance of WANG LING. *Cambridge University Press, Bentley House, 200 Euston-road, London, N.W.1.* (52*s.* 6*d.*)

It has been difficult for the Western scientist to take Chinese science seriously. For several decades there has been a steady increase in the flow of writing on the "wisdom of the East," but most of this material has been couched in language with which the scientist scarcely feels at home. Now, however, description, evaluation and interpretation are undertaken by a Fellow of the Royal Society—and one who has emerged from specialisation with time enough to develop authority in a wider field. Dr. Needham's special subject is biochemistry—a discipline particularly favourable, perhaps, to a feeling for the forms of Chinese thought, which are rooted in the idea of organism.

Another difficulty has been dwindling over the last 50 years. During this period, in the West, there have been developed the theory of relativity, the uncertainty principle, the quantum theory and other conceptual models that seem to bear a closer relation to traditional Chinese thought than to Nineteenth Century scientific orthodoxy. A dilettante, at least, may feel some formal similarity between Sir Arthur Eddington's uranoid and the concept of Tao or the Confucian doctrine of the mean; between the mathematical theory of groups and the Chinese Book of Changes. The fact that there is much contention over the new scientific epistomology is irrelevant; the important thing is that many ideas that would formerly have been dismissed as mystical mumbo-jumbo are now considered worthy of serious criticism by scientists reared in the Western tradition of thought.

It is not only to the historian and the philosopher of science, however, that this work will be stimulating. In the development of technology, invention is primary. Novelty, whether on the grand scale or in matters of detail, emerges as the result of an imaginative leap. The communicable disciplines of scientific thought, systematising existing knowledge, may provide the platform from which the leap is made and the criteria by which the result is assessed, but much invention is unaccompanied by anything that can be regarded as a consciously applied theory. An impressive Table in this volume gives the time lag in transmission of several techniques from China to the West, ranging from one century for metal movable type through nine to ten centuries for the wheelbarrow, to 15 centuries for the square-pallet chain-pump. Of all of these, it might be said that their invention depended on no theory or body of systematised knowledge. They could either have been "hit on" or have been evolved by trial and error to meet a need. Dr. Needham's epithet is "empirical genius and primitive theory." Yet we can recognise the pattern: it is not so very different from our own in Europe up to the Sixteenth Century, and it is a pattern that still characterises our older technologies. If the younger branches of engineering—electrical, electronic, aeronautical—appear as happy marriages of theory and practice, the older ones such as building do not. And we are familiar with the predicament in which, faced with a practical problem, one may long with all the fervour of heresy for a little more empirical genius in exchange for a wealth of sophisticated theory.

Acquaintance with forms of thought different from our own, but not so different as to appear irrelevant, is always valuable. Moreover, in the interactions between China and the West we may detect a vague pattern to encourage our interest. Before 1600, the flow of ideas was from East to West. Since then it has been in the reverse direction. Now we find that our most advanced thinkers are breaking with Aristotle and are formulating, for the first time in the West, ideas that have been implicit in Chinese philosophy for millenia. There is a growing realisation that analysis is not enough, even in the non-biological sciences; carried beyond a certain point in one direction it discovers only indeterminacy, in another direction only irrelevance; in a third direction it results in the confusion of tongues between specialists. Analysis is only a tactical weapon. Chinese thought has been concerned rather with the general strategy of human achievement. Human societies and institutions, large and small, fall on bad times when either strategy or tactics receives undue emphasis at the expense of the other. Perhaps it was through an inaptitude for analytical thought that the Chinese lost their lead to the West for three centuries; it may be that we are now ready to learn from their aptitude for thinking in terms of process and organism.

This is the first to appear of the seven volumes planned. It presents the credentials of the work, outlines the structure of the Chinese language, lists sources, and gives a general background, geographical and politico-historical, to the period studied—roughly from 1500 B.C. to the beginning of the Seventeenth Century when, with the mission of the Jesuits, the autonomy of Chinese science drew to a close. The last, and longest, section in this volume deals with the conditions of travel of scientific ideas and techniques between China and Europe.

The second volume is also to be general in its scope, presenting a history of Chinese scientific thought. The next four volumes will cover the separate sciences: mathematics, astronomy, meteorology, geography, geology, physics, engineering and technology, chemistry, biology, agriculture and medicine. The final volume will examine how it was that modern science was destined to develop in the West rather than in the East, in spite of the East's apparent lead in technology a few centuries ago. The promise of a most fascinating study.

Classified Lists of Historical Events: Mechanical and Electrical Engineering. Compiled by G. F. WESTCOTT. Published for the Science Museum by *H.M. Stationery Office, Kingsway, London, W.C.2.* (2*s.*)

The study of the development of technology is the youngest of all the branches of history, and in some respects it is the most difficult. To discover, and what is more important, to interpret and evaluate, the facts in any branch of technological history requires much more than a knowledge of historical research procedure. An engineering historian must be primarily an engineer, a metallurgical historian must be familiar with the science of metallurgy, and he who would study the history of shipbuilding must know a great deal about how ships are built. So it is in every branch of technological history: the student who is to achieve anything worth while must be both technologist and historian. Because of this need it is usually advisable to concentrate in a fairly narrow field. The historian cannot, however, ignore other spheres. The development of the steam engine, for example, was dependent upon parallel advances in metallurgical practice and manufacturing methods, which made suitable materials available at the right time, and in turn the metallurgical industries benefited greatly from the new source of power which the steam engine provided.

Just as one branch of technology has always depended upon others, so must the student of any one branch of the history of technology depend upon the work of other historians to give him the correct background. It is a great help if he can have access to comprehensive and, above all, reliable sources of information, which can be consulted easily. In the considerable amount of historical literature which has become available in recent years there is little enough which easily meets his need.

The present publication is outstanding in that it provides a ready source of information covering a very long period—from the dawn of history to the present day—and it will have a value to the historian out of all proportion to its modest size and price. It is, as one would expect of a Science Museum publication, authoritative and in every way up to the high standard of that body's previous publications. The historian will appreciate the fact that, in accordance with the best modern practice in historiography, full source references are given throughout. To list the principal events in the history of mechanical and electrical engineering over such a long period—from approximately 500,000 B.C. to the present day; from the discovery of the uses of fire to the harnessing of atomic energy—is a considerable task, which Mr. Westcott has carried out with marked success. The arrangement is chronological, which is perhaps the only one possible in a work the size of the present one. To find the date of a particular event, therefore, may involve some little searching, unless the user of the list has an approximate idea of the date he seeks, when it will be discovered very easily. To search for a date is no hardship; the list is set out very clearly, and test searches have shown that it is simple enough to use. In any case, the only alternative would have been to provide a cross-index of events, which would have increased the size and cost of the publication greatly. The historian will find the list a valuable source of reference, and will look forward to the publication of further lists, which are mentioned in the introduction.

Those who are not specifically interested in technological history may inquire if the publication is of any use to them. It would be possible to make out a good case for saying that it is. No engineer can escape the impact of history. When he is learning his profession he is learning a great deal of history, though he may not realise it at the time, for all the basic principles of engineering are really nothing but history, discovered at some time in the past and recorded, perhaps not always consciously, for use in the present and future. When the engineer is qualified, and produces new designs, he is still involved in history, for he is making it.

History by dates, as in the present compilation, may be thought by some to be dull, though many historians would disagree. Nevertheless, even an engineer with no particular interest in history might find that a perusal of the list will give him food for thought. He may, perhaps, be surprised to learn of the antiquity of some of the things with which he is familiar; to find, for example, that toothed gear wheels date from *c.* 500 B.C., that the screw is only about 100 years younger, and that the screw-press was invented some time in the second or first century B.C. Similarly, he may be interested to find that the weighted-lever safety-valve was used on Papin's "digester" of 1681, and that the chain-grate stoker was patented in 1834. If he is unimpressed by these and the many similar facts which are listed, he might pause to reflect that although man first learnt how to use fire about 500,000 B.C., it is often used to-day with the same disregard for waste of fuel, and that half a million years have not brought quite so much progress as we may think. There is much more that might be said in a similar strain, and there are many facts in the list which might induce in the reader a feeling of humility, as the study of history so often does.

One last word. History is not solely concerned with what happened in ancient times, or even in the last few centuries; it is simply a continuous record of events. Developments have been so rapid in many branches of engineering and science in recent years that it is difficult to keep pace with them. In the atomic energy field, to take but one example, there are probably few people who could say, in correct chronological sequence, how this new science developed. Mr. Westcott's list will provide that information, in concise form.

INFLUENCE OF SPACE FLIGHT ON ENGINEERING AND SCIENCE*

By Milton W. Rosen†

Perhaps some of you have noticed the inversion of the engineer as between the titles of Dr. Dorey's paper‡ and mine. Since I am confident that Dr. Dorey has chosen correctly, it behoves me to explain why I should elect to place the cart before the horse. Whereas, in the case of sea transport the activity existed long before the engineer bent his mind to it, space flight has yet to be achieved, even though it has occupied the scientific mind for several centuries. We are concerned here with an idea and the efforts that have been and are being made to implement that idea.

Within the last few years many scientists have predicted seriously and confidently that human beings from the earth would, in the foreseeable future, travel to the moon and the nearer planets. The ranks of those who would dispute this prospect are diminishing rapidly. Although much of the progress is still guarded by military necessity, space flight is emerging as an activity in its own right—one that can command the efforts of many engineers and scientists.

In the United States the exploration of the upper atmosphere, the frontier to space, is a vigorous and continuing activity. Pilots of rocket aircraft have experienced conditions approximating to those in free space, if only for a few minutes. The effect of space flight upon the human organism is being investigated—the U.S. Air Force maintains a Department of Space Medicine.

There is an international organisation devoted to the promotion of space travel and there are space flight societies in 23 countries. Numerous journals exist wholly or in part for the publication of papers on astronautics and its allied fields—notable among these for the quality of its articles is the Journal of the British Interplanetary Society.

DISTANCE IN SPACE

In the next few pages I will try to explain how the present state of affairs came about and also to forecast what might be the future influence of man's effort to travel in outer space.

The ancients, except for a few rare individuals with greater insight, conceived of the world as an enclosure; they stood upon the earth at the bottom and gazed upward at a blue ceiling upon which a multitude of lights, a few great and many small, seemed to move under the influence of an unseen hand. The atmosphere filled this enclosure and it was believed that if man had wings he could fly to the ceiling and determine the source of the lights. If a few philosophers guessed more nearly at the truth, certainly the average man had no better conception of the universe than the fanciful picture just described. There could be no valid idea of space flight until Copernicus, Kepler, and Galileo placed the earth in its true relation to the universe and at the same time gave dimensions to space.

When at last the moon and the planets were found to be material bodies not unlike the earth, it was possible to ponder whether the immense separating distances could be traversed by man or any man-made device. The situation was made even more discouraging when, in 1686, Newton[1] defined the nature and the magnitude of gravitational attraction. If previously there had been some fanciful hope of visiting celestial bodies, now surely it appeared that man was destined to remain forever a prisoner of his own planet. In view of the great distances, it seemed unlikely that the atmosphere could extend through interplanetary space, and any suspicion that it might was laid to rest when Torricelli's barometer was carried to a mountain-top and taken aloft by the early ballonists.

Although Newton brought man face-to-face with one formidable aspect of the problem, namely gravity, he also provided, in his three laws of motion, the key that would unlock the door to space. The fundamental equation of rocket action in free space and hence of space flight:

$$V_b = C \log_e \frac{M_o}{M_b}$$

where V_b = velocity of rocket at end of burning
C = velocity of exhaust jet
M_o = initial mass of rocket
M_b = mass of rocket at end of burning

is derived by integrating Newton's third law of motion. Nevertheless, more than two centuries were to pass before anyone performed the integration or realised that the simplest embodiment of Newton's third law, a rocket, is the only machine capable of propelling itself in a vacuum.

While science gave no solution and, indeed, many scientists despaired of finding one, the dream of travel to celestial bodies was kept alive in fiction. One of the earliest references to rockets for propelling a space ship is found in the writings of Cyrano de Bergerac[2], but it is doubtful that Cyrano understood the rocket's essential rôle. Perhaps the most famous novel about space travel is Jules Verne's "From the Earth to the Moon." Although Verne had expert scientific advice, he chose an impossible means of projecting his space ship—it was fired from a long cannon sunk in the ground. Probably, Verne knew that no human could survive the acceleration of his projectile and that the projectile itself would disintegrate under the tremendous forces imparted to it. Yet millions of readers believed his story, many thought it had actually been accomplished—so great was his art—and he created a myth that had to be destroyed before any scientific progress could be achieved. In his novel "The First Men in the Moon," H. G. Wells[4] felt no necessity for scientific rigour and he conjured up a gravity-defying substance which he called "Cavorite."

ROCKET ACTION AND ESCAPE FROM THE EARTH

By the beginning of the Twentieth Century the physical sciences had advanced to the point where it was inevitable that someone would develop a valid theory of rocket action and would apply the theory to the problem of escape from the earth. The task was accomplished by three men working independently in three different countries. The three had much in common—they were teachers, one at a small university, the other two in secondary schools. Each one pondered the problem for many years before committing his findings to publication. But what is most important, all three were motivated by the desire to explore interplanetary space and presented their findings with conviction, even though they were regarded by most of their contemporaries as prophetic dreamers. The men and their works are now well known. They are:

Ziolkovsky—*The Exploration of Cosmic Space by Reaction Machines*—1903.

Goddard—*A Method of Reaching Extreme Altitudes*—1919.

Oberth—*The Rocket Into Interplanatary Space.*—1923.

Any one of these three publications, had it been widely read and accepted, would have sufficed to lay the groundwork for space travel, because each man clearly understood and asserted the following fundamental concepts:

1. That escape from the earth is possible by the application of a moderate acceleration over a substantial period of time—at least several minutes.

2. That such acceleration can be produced in a vacuum by a rocket.

3. That the rocket must (*a*) have high thermal efficiency (i.e. high velocity of the ejected matter) and (*b*) consist mainly of propellant material (i.e., have a high ratio of fuel weight to total weight).

4. That high thermal efficiency would be obtained most readily from the chemical combustion of liquid fuels.

Ziolkovsky[5] started by examining Jules Verne's cannon and also the balloon as a means of reaching very high altitudes. Both approaches died

Fig. 1 A V-2 rocket, equipped with instruments for upper air research, ascending from a proving ground in New Mexico. The V-2 was the biggest single advance in the practical development of rocket flight.

* Paper read before Section G of the British Association at Bristol on Thursday, September 1.

† Naval Research Laboratory, Washington, D.C.

‡ "The Influence of the Engineer on Sea Transport and Trade." An abridged version of Dr. Dorey's paper was given in ENGINEERING for September 9, 1955, page 331.

quickly under mathematical analysis. He proceeded next to the rocket and developed the fundamental equation previously noted. Realising that energetic fuels were required, he determined from thermo-chemical calculations the heat release of various liquid combinations. When he computed the velocity that could be attained, in theory at least, he realised it was sufficient for escape from the earth.

FIRST FLIGHT OF A LIQUID-FUELLED ROCKET

Goddard,[6] alone of the three, proceeded from experiment to theory. Using smokeless powder in a heavy-walled steel combustion chamber he produced a jet velocity of almost 8,000 ft. per second, a seven-fold improvement over ordinary rockets and the highest velocity of matter attained up to that time outside of electrical discharge tubes. Also, he proved by tests in a vacuum that a rocket does not produce its force by pushing on the air behind it, a fact he knew from basic physics, but that he felt had to be demonstrated. He observed correctly that the jet velocity was greater in a vacuum, but he attributed it erroneously to more efficient ignition. Although Goddard did not turn to liquid fuels until after his basic paper was published, he achieved the first flight of a "liquid" rocket, an event that took place on March 16, 1926. Goddard[7] continued his experiments for more than two decades during which time he developed, in rudimentary form, almost every component of modern rocketry. Not one of his components would be considered reliable by present-day standards; realising the prodigious task he had set out to accomplish, he would repeatedly add a new component before perfecting the previous one. In retrospect, it appears that Goddard was attempting, single-handed, to encompass the entire field of liquid-rocket development, a task that would eventually tax the abilities of thousands of engineers and scientists.

Oberth,[8] in his treatise, gave the most complete theoretical analysis and carried it farther into the realm of space travel than either of the others. He stated at the outset the four propositions he would attempt to prove:

1. Considering the present state of science and technology, it is possible to build machines that could rise beyond the atmosphere.
2. After further development these machines will be able to attain such velocities that, left undisturbed in the depths of outer space, they will not fall back to the earth and will even be able to leave the zone of terrestrial attaction.
3. These machines could be constructed so as to transport human beings, probably without damage to their health.
4. Under certain economic conditions the construction of such machines might be profitable.

Oberth began by developing the theory of the liquid rocket and describing its construction. He proceeded to discuss applications of the rocket, first as a high-altitude sounding vehicle, then as an earth satellite, and finally as a spaceship for interplanetary travel. He developed the concept of synergic (minimum energy) ascent trajectories. Without doubt, almost every later book on space flight owes much to Oberth's encompassing study.

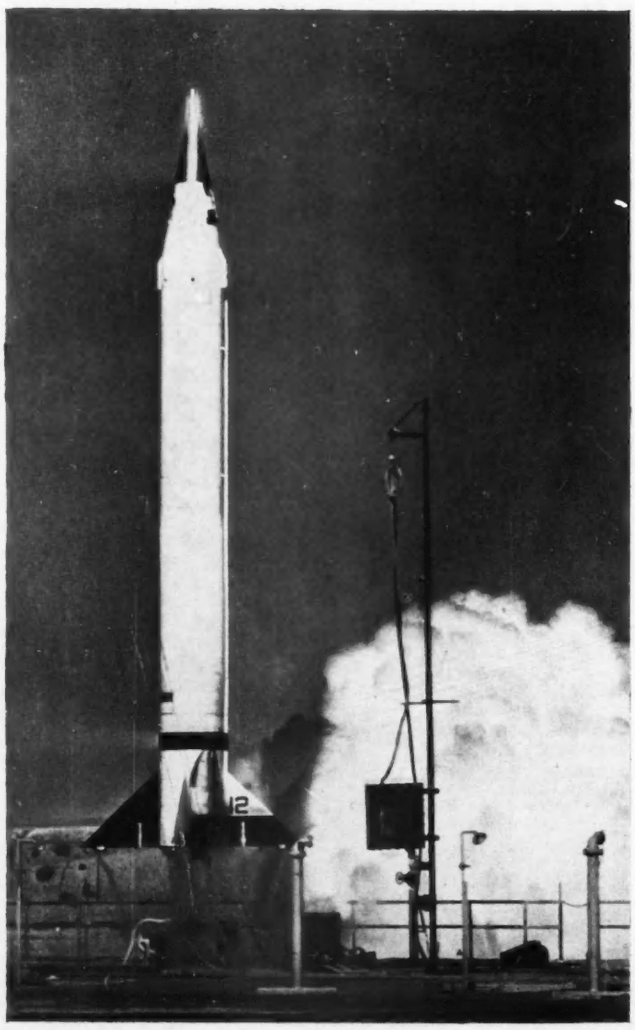

Fig. 2 A Viking 12 taking off on a flight in which it reached a height of 144 miles above the earth's surface. Viking rockets have been much used in America for exploration of the upper atmosphere.

EXPERIMENTAL PREPARATION

Whereas the first quarter of this century provided the theoretical background for space flight, the second 25 years may be viewed as the period of experimental preparation. It saw the liquid-fueled rocket develop as a practical engine for the propulsion of aircraft and guided missiles. Many fuels and oxidisers were explored, a few of which saw widespread use. An assortment of auxiliary hardware—pumps, turbines, valves and regulators—was developed to feed and control the rocket motor. The steering of a large rocket vehicle was mastered by means of gyroscopes and jet controls. Great progress was made in the aerodynamics of supersonic flight, in structural design, and in the use of high-temperature materials.

Of the early experimenters three groups were most noteworthy. The work of Goddard as an individual has been referred to previously. In Germany the *Verein für Raumschiffahrt*, fired by Oberth's monumental work, undertook to develop a small workable rocket called, appropriately, *minimum-rakete* (Mirak—for short).[9] In the course of several years they made hundreds of static firings and numerous brief flights. The American Interplanetary Society drew its inspiration largely from abroad, so secretive was Goddard about his experiments. Indeed, when in May, 1933, the Society finally achieved a first liquid-rocket flight, they were unaware that Goddard had progressed far beyond his first flight seven years before. It is unfortunate that the British Interplanetary Society was prevented from experimenting with rockets, a situation frequently lamented by its founder, Mr. Philip Cleator.[10]

V-2, AEROBEE, AND VIKING

The V-2, whose development started in the middle of this period, was the biggest single engineering advance in the field of rocketry (Fig. 1). By applying thousands of engineers and scientists in a concerted effort, the German government was able in six years to transform the liquid-fueled rocket from a small, sputtering vehicle, capable of ascending a few hundred feet, into a giant projectile with a range of 200 miles and a velocity of one mile per second. The V-2 was a material embodiment of Oberth's ideas and, although he conceived the liquid rocket as a vehicle for space travel, he also foresaw its possible use as a bombardment weapon. Actually, he hoped that the rocket missile would be a deterrent to, rather than a tool of, war.

After the war the major activity leading to space flight took place in the United States in the form of upper-air research with instruments carried in rockets. In a continuing programme, scientists from government laboratories and universities explored the upper atmosphere using at first captured V-2 rockets and later, as they became available, Aerobees and Vikings. Both Viking and Aerobee were designed specifically for probing the atmosphere in the region between 50 and 150 miles above the earth. Fig. 2 shows a Viking 12 taking off, and Fig. 3 a photograph taken at an altitude of 144 miles. A few of the more important accomplishments of this programme are noted. Knowledge of the pressure, temperature, density, and ionic content of the atmosphere has been extended up to 135 miles by direct measurements. The solar spectrum has been recorded in the far ultra-violet. X-rays have been detected in solar radiation and their rôle in the formation of the ionosphere has been postulated. The number and the mass distribution of primary cosmic rays have been recorded in emulsions carried aloft in rockets. Small animals, monkeys and mice, were sent aloft and their physiological reactions observed during a period of weightlessness. For nine years man has been exploring the frontier of space as a prelude to flight beyond the atmosphere.

AVIATION AND ROCKETRY

It is always tempting to draw parallels and it might appear, at first glance, that the advance toward space flight parallels the progress of aviation, with the latter preceding in time. The same elements of progress are evident in both fields, but one cannot fail to note the differences and contrasts.

Although much theoretical work had been done on fluid mechanics and experiments performed in wind tunnels and with gliders, there was at the time of the first mechanical flight no adequate theory to explain the lift of a winged vehicle.[11] We knew that the Wright Brothers' plane flew, but we could not explain why or how it flew. By contrast, the motion of a rocket, as we have seen before, was well understood before Goddard's first flight attempt. This is no paradox—it is apparent that the mathematical treatment of flight within the atmosphere is much more difficult than the analysis of flight in free space.

In both fields there was a period when development was nourished mainly by amateurs; in aviation it was the first decade of this century, for rocketry the late twenties and early thirties. In both cases the advance was given great impetus

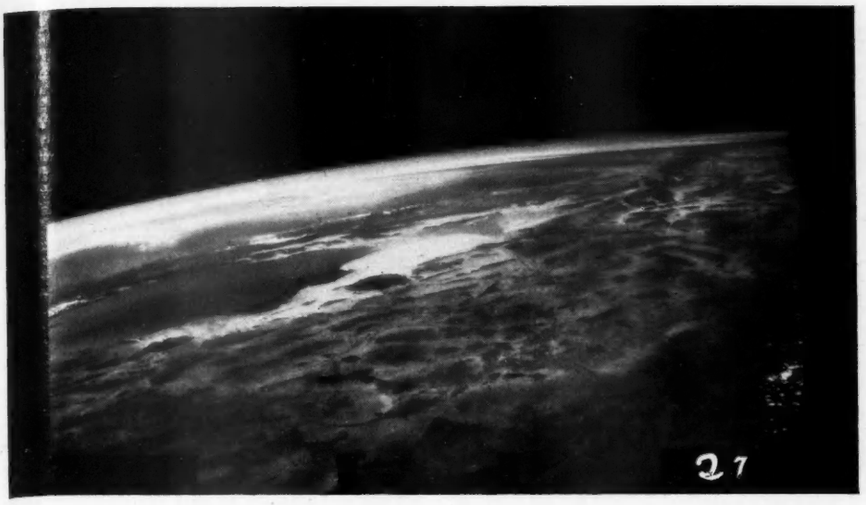

Fig. 3 A photograph taken from a Viking 12 at a height of 144 miles. The gulf of California can be seen left centre; the horizon is 1,070 miles distant and extends across the picture for 750 miles.

by a war; the first World War for aviation, the second for rocketry. But I doubt if there is in the history of aviation any single step forward comparable in magnitude to the creation of the V-2. Aviation has been characterised by gradual, steady development, fostered to a large extent by its economic returns as well as its military advantages. There have been several significant milestones; one of the most noteworthy was the development by Sir Frank Whittle and others of the turbo-jet engine, which in the short space of a dozen years has completely displaced the piston-driven propeller in high speed military aircraft and may soon dominate the field of commercial aviation.

In pursuing this rather loose parallelism I have tried to estimate what period in the history of aviation corresponds to the present status of space flight. It seems to me that we are now at a point roughly corresponding to the period before Lindbergh's historic flight across the Atlantic. The significant event we are awaiting is the first orbital flight of a manned earth satellite.

In both cases, at the time being considered, the vehicle had been developed to a reasonable degree of reliability and many flights of shorter range and duration had been made. But again, there is a significant difference. Aviation has always implied manned flight—in rocketry most of the progress thus far has been made in unmanned, automatically-controlled vehicles. Our technology has advanced to the point where we need not risk human life in experimental rocket flights—on the road to space, instruments will always go first and will point the way for men to follow.

MANNED SATELLITES AND RETURN TO THE EARTH

Prior to establishing the first manned satellite two important techniques will have to be mastered. First, there will be a period of experimentation with unmanned, instrumented satellites during which time problems of propulsion, staging, and navigational control will be worked out. The environmental hazards—cosmic radiation, meteors, solar heat (and the absence of it), and possibly weightlessness—can be evaluated. World-wide realisation that this first problem is being attacked vigorously came when, on July 29, 1955, President Eisenhower announced that the United States would launch small instrumented satellites during the International Geophysical Year (1957-58). By their statements in support of the President's announcement, many noted scientists attested to the feasibility and usefulness of the instrumented satellite. It is significant, also, that the United States invited international co-operation and offered to make its scientific findings available to all nations.

The second problem is the one of safe return to the earth's surface. The relative speed of roughly five miles per second between the orbiting vehicle and the earth's surface must be brought to zero. Obviously, this will be done by allowing the satellite to transfer its energy to the atmosphere. But this process must be controlled with great precision, lest the satellite absorb too much of the energy in the form of heat. Much will be learned by observing the return of instrumented satellites, but the final preparatory steps will probably involve manned flights st gradually increasing re-entry speeds.

I have placed Lindbergh's flight and the first manned satellite in juxtaposition because one has and the other will, I believe, so excite the world's imagination that future progress will be greatly accelerated. One cannot say when the desired event will take place—much hard work remains to be done—but it is not uncommon for scientific achievements to precede their predicted arrival. The mechanical components, engines of sufficient power and controls of requisite precision, are within sight. If it is argued that the human hazards are great and, at present, poorly understood, let it be remembered that the first orbital flight need only be brief—a matter of several hours. In this respect the ordeal may be less prolonged than Lindbergh's flight, but certainly no less demanding upon the pilot's judgment and courage.

We have seen that although space flight is yet to be achieved, its prospect has had, in the last fifty years, an appreciable influence upon science. The greater influence by far lies in the future. The advances in our technology necessary to achieve manned flight in space and those required to exploit it can be readily delineated. But a more important result will, I believe, be the impact of space flight upon scientific thought and education.

A WORTHY SCIENTIFIC GOAL

In America to-day we are faced with a serious shortage of engineers and scientists even though the demand is great and the remuneration is ample. Almost every prospective technical graduate of our universities is showered with offers of employment and our newspapers and magazines are filled with advertisements for men with technical training. The most appalling aspect of this situation is that it is likely to continue for many years. A recent survey shows that the study of physics in our public high schools has been declining for more than half a century. Whereas in 1895 more than 95 per cent. of high school graduates had taken a course in physics, by 1952 only 21 per cent. of graduates had ever studied it.[12] For many years the increase in high school enrolment more than offset the decrease of specialisation in physics, but now the waning interest is taking its toll. To-day, only about half of the public schools offer a course in physics, and a quarter of these have no laboratory facilities. There is a critical shortage of science teachers, due in part to the attractions of industry, but more to the lower status and wages accorded the teaching profession. But these factors can be remedied with sufficient effort—a deeper and more serious cause is the lack of interest on the part of our youth. Why do they turn away from a career in science? We can only grope for the answer. Perhaps they sense, better than their elders, that too much of our scientific talent is engaged in the unproductive task of developing weapons for war. Is there much inspiration to devote one's life to this end, especially when we are rapidly approaching the borderline of total destruction?

I believe that space flight might serve in no small measure to turn men's minds toward a more appealing scientific goal. As the exploits of Cabot, Drake, and Davis inspired many generations of Englishmen to turn to the sea, so may the first astronauts reawaken our youth to the romance of scientific exploration.

A report of the discussion on this paper is on page 368.

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IRRADIATED MATERIALS AND PLASTICS

T.I.'s New Laboratory

A research station is to be established at Walsall to tackle problems related to irradiated materials, development of plastics and control engineering. Sponsored by the Tube Investment Group of companies, the new station will supplement facilities already available to the Group at their laboratories at Cambridge and Birmingham, and will be opened early in October.

The Irradiated Materials Section at Walsall will be directed by Dr. A. Charlesby, D.Sc. Ph.D., formerly of the Atomic Energy Research Establishment, Harwell. Its development work will cover a wide field, but will be particularly concerned with irradiated plastics. The materials will be irradiated in the first instance at the Group's laboratories at Hinxton Hall, Cambridge, where an electron accelerator is now being installed.

The Plastics Development Section will be directed by Mr. J. E. Gordon, B.Sc., formerly head of the plastics development organisation of the Royal Aircraft Establishment at Farnborough. This section will be concerned with the development of processes and the necessary machines to be used in the plastics industry to take advantage of the chemical advances of recent times, with the streamlining of production techniques and their impact upon design.

The third team at Walsall will operate under the direction of Mr. C. A. Cochrane, M.A., on control engineering, including the application of electronic techniques to industrial processes.

LINEAR ACCELERATION OF CHARGED PARTICLES TO HIGH ENERGIES*

ELECTRON ACCELERATORS: INDUSTRIAL AND MEDICAL APPLICATIONS

By C. W. Miller, M.SC., F.INST.P.†

The first part of this paper was given in the issue of September 9, page 340. It considered the development of linear accelerators during the past 25 years, starting with the work of Cockcroft and Walton. Distinction was made between direct and indirect acceleration, and certain proton accelerators were described. This second and concluding part describes types of electron accelerators, and mentions applications and engineering problems of linear accelerators in general.

War-time radar development made available in 1945 a new type of radio-frequency power generator, the magnetron, with which pulse powers of the order of 2 MW at frequencies of about 3,000 Mc/s. (λ = 10 cm.) could be generated. Further, such valves could be operated at a duty cycle such that mean powers of about 2 kW were possible. Extension to even higher powers seemed possible and the background of microwave techniques caused several groups to consider the application to electron acceleration. Many schemes were suggested, some of which, including ideas using spiralled or folded waveguides, have not, so far as the author is aware, actually been built. Some of these schemes are shown in the review by Fry and Walkinshaw.[22] Perhaps the most immediately obvious method of acceleration was to utilise the fields in a single resonant cavity and subsequently to extend this to multiple cavities, but attention was also soon directed to the use of travelling-waves in distributed systems, i.e., in loaded waveguides. In the limit a distinction between the two methods becomes somewhat artificial since if the travelling-wave is reflected so as to produce a standing wave the result is a device which owes something to both types of machine and indeed can be considered from either point of view. We shall, however, for purposes of review, make the distinction. As regards travelling-wave accelerators work progressed concurrently and independently on similar lines chiefly in America (Stanford University) and in England (a linear-accelerator team at the Telecommunications Research Establishment, later at the Atomic Energy Research Establishment) but although there was much common ground there was one important difference in approach. The American effort was aimed essentially at producing electrons of energy as high as possible for nuclear research; in England much more modest energy was considered, but high output currents were studied with consequent emphasis on efficiency in terms of the ratio of beam power to radio-frequency power. We shall, therefore, as is shown in Fig. 1, make a distinction between high-energy low-current machines and the more efficient low-energy high-current equipments.

RESONANT-CAVITY ACCELERATION OF ELECTRONS

Typical of the resonant-cavity acceleration of electrons we may consider the work of Mills.[28] His equipment was the basically simple case of a single resonant cavity, operating in the E_0 mode having "nosed in" electrodes with a hole for the passage of electrons along the axis of the cavity. A 25-cm. magnetron of 600 kW output was used and a mean beam current of 70 μA was obtained at an energy of 1·1 MeV. It will be noted that although in this case the highest voltage used outside the cavity is 30 kV the full voltage of at least 1·1 MV exists across the electrodes of the cavity, indeed a single cavity is a direct accelerator. The use of multiple cavities is required to obtain indirect acceleration and typical of this in a simple form may be quoted the three electrode-gap scheme of Allen and Symonds.[29] In this structure three cavities are coupled by means of annular slots such that adjacent cavities are excited in antiphase and electrode spacings are arranged to match the increasing velocity of the particle. Both arrangements are shown in Fig. 8. Other workers have considered extension to many more cavities and typical of such work is the suggested arrangement given by Newbury in the discussion of Mills's paper.[28] This was for a 4-MeV equipment powered by a 10-cm. magnetron. A major difficulty in any resonant accelerator is the feeding of power to the highly resonant system and when many coupled cavities are used there is also the possibility of resonance in unwanted modes at frequencies close to the design frequency. Such equipments are usually stabilised by feeding some of the power into an absorbing load but this is, of course, wasteful and has an adverse effect on the efficiency.

The most ambitious scheme using the methods outlined above is that of the Massachusetts Institute of Technology accelerator.[30] This utilised a series of cavities coupled through central holes as shown in Fig. 8 and since a high injection energy was used a uniform structure was possible. The equipment is 21 ft. in length being built as seven sections each 3 ft. long and comprising 16 cavities. The equipment operates at a frequency of 2,800 Mc/s (λ = 10·7 cm.) power being supplied from 21 tunable magnetrons (three to each section). Since it is essential that all parts of the accelerator be supplied with power in exactly correct phase relationship the use of a multiplicity of magnetron oscillators presents an extremely difficult problem. In the M.I.T. equipment the solution has been found in exciting one section in advance of the others and using coupling so that all oscillators may start in phase and then controlling frequency of all oscillators to such limits that a drift out of phase during the pulse is of negligible amount. Since, however, restriction on any phase error is extremely tight this means frequency control to a few parts in 10^4 and the M.I.T. project may be regarded as a very great achievement in the microwave art. The equipment takes electrons at an energy of 2 MeV from a Van de Graaff machine and accelerates them to 18 MeV. An average current of 1 μA, corresponding to pulse currents of about 10 mA, has been obtained.

TRAVELLING-WAVE ACCELERATORS

When power is propagated along a waveguide of smooth-walled circular cross-section the fields set up are of the form shown in Fig. 9 (*a*). There is an axial component suitable for the acceleration of particles but the velocity of propagation is always greater than light velocity. The inclusion of iris diaphragms as shown in Fig. 9 (*b*) reduces the velocity of the wave while maintaining an axial component of field. It is possible by correct choice of iris dimension to produce any desired velocity of propagation and hence a loaded waveguide forms a structure which may be used for electron acceleration. Electrons may be injected along the axis of such a waveguide with modest energy, choosing waveguide dimensions to give wave velocity to match the low velocity of the electrons. The electrons travel continuously in an accelerating field acquiring energy and increased velocity, the dimensions of the irises being varied suitably. In this early stage of the accelerator, usually known as the "buncher," since particles are collected about some discrete phase with respect to the radio wave in the same way as was described in relation to the proton accelerators, energies of the order of 1 MeV are attained. Thereafter velocity is almost equal to that of light and uniform structures may be used. It should be emphasised at this stage that although the accelerating structure appears very similar to that of Fig. 8 (*c*) used for the cavity type of accelerator there is an important difference. For this multiple-cavity arrangement the spacing of the electrodes is fixed and is equal to the distance travelled by an electron in one half-period of the excitation whereas in the travelling-wave arrangement the spacing is less than this, being usually 0·2 to 0·25 of the wavelength of propagation in the waveguide and determined from a consideration of power loss. An important dimensional parameter in a travelling-wave accelerator is $\frac{a}{\lambda}$, i.e., the ratio of iris hole radius to the free-space wavelength of the radio power. This ratio determines the relationship between the power flow and the accelerating field, i.e., the series impedance of the guide and also the losses and hence the attenuation of the structure. In general, a small $\frac{a}{\lambda}$ gives high accelerating field for a given power but increased attenuation. Consequently, in machines where a small current at high energy is required the smallest value of $\frac{a}{\lambda}$ consistent with frequency tolerance, $\left(\text{another factor dependent on } \frac{a}{\lambda}\right)$ would be used. When, however, higher efficiency and maximum power output is required a somewhat greater value would be used, possibly either increasing power input or length of accelerator to gain the required energy. Values of $\frac{a}{\lambda}$ used range from 0·1 to 0·2.

POWER EFFICIENCIES

The development of travelling-wave accelerators at T.R.E. and at Stanford were at first on very similar lines. A short accelerator producing electrons at 0·5 MeV was first operated at T.R.E. by Fry *et al.* in November, 1946, and this was followed by a 2-m long equipment operating at about 3·5 MeV.[32] At Stanford electrons were first accelerated in 1947 and eventually a 12-ft. machine (known as Stanford Mark 1)[33] was constructed and operated at an energy of 6 MeV. Also among the early work should be noted the construction of an accelerator of 1-m length, giving an energy approaching

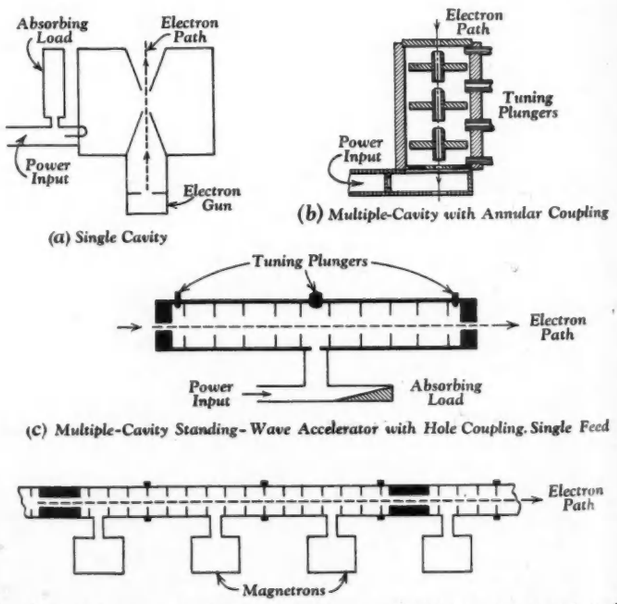

Fig. 8 Linear accelerators using resonant cavities.

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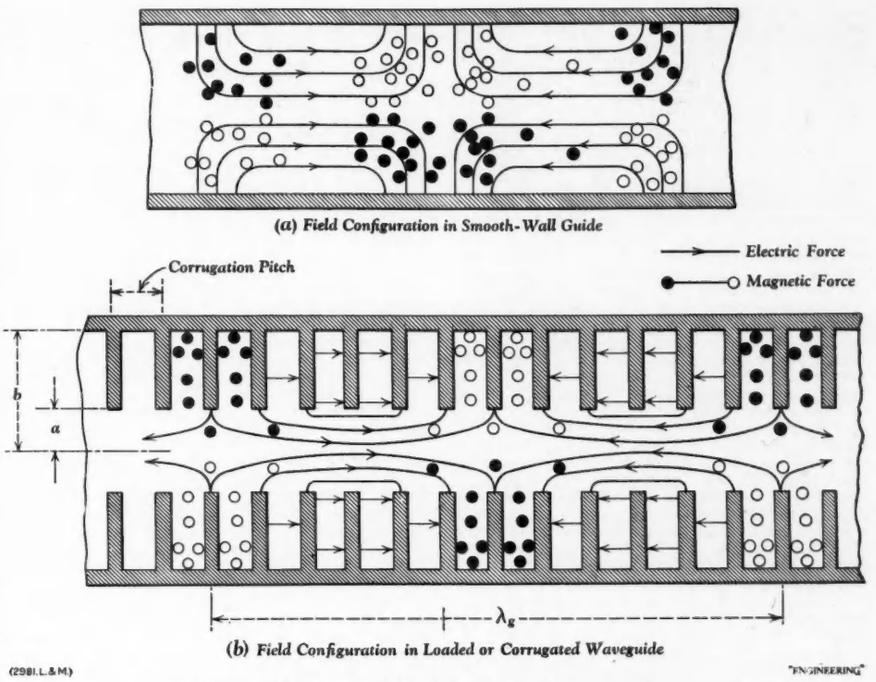
† Research Department, Metropolitan-Vickers Electrical Co., Ltd.

1 MeV, by Starr, King and Lewin[34] of Standard Telephones and Cables, Limited. All the above equipments operated from magnetron power sources with a wavelength of about 10 cm. From the first, British interest had centred on efficient machines and considerable attention had been given to careful design of the bunching section and the focusing of the beam by use of axial magnetic fields to overcome the radial forces of dispersion associated with the accelerating fields. American interest, on the other hand, was directed to extremely high energies and efficiency (in the power sense) was of little interest; efficient bunching and focusing were therefore of secondary importance. As a consequence, developments in the two countries have, after the initial work, followed rather different lines. In America it was clear that it would be essential to use multiple power sources in order to energise very long accelerators and this led to the development of high-power klystron amplifiers. In Britain development continued using a 2-MW peak, 2-kW mean power magnetron and following the success of the early equipments the use of a travelling-wave linear accelerator for X-ray therapy was proposed. Development of such an equipment was started in 1948 and was carried out by the Metropolitan-Vickers Electrical Company in collaboration with the Atomic Energy Research Establishment (which had taken over the linear-accelerator team of T.R.E.) and the Medical Research Council. This development not only provided much engineering experience, both as regards the accelerator itself and its adaptation to clinical use, but also as a result of much investigational work provided a large amount of design information for future equipments. The immediate outcome was, however, a fully engineered clinical equipment using a 3-m length of accelerator waveguide which was installed at Hammersmith Hospital in 1953 and has been in continuous clinical use since August of that year. A most interesting feature of this equipment is that it employs radio-frequency power feedback, a scheme suggested by Harvie and Mullett[35] and illustrated in Fig. 10. In this scheme radio-frequency power from the output end of the accelerator is returned and by means of a bridge circuit is combined with the incoming power thus giving an increased power flux in the accelerator. By this means it is possible to design an equipment for a given energy and length using a lower $\frac{a}{\lambda}$ with consequent easing of frequency tolerance. The performance of the equipment can be summarised as 7·5 to 8 MeV for beam currents up to 40 μA mean, corresponding to pulse currents of about 60 mA [36, 38].

The logic of the next development can be followed if we consider the effect of the variation of input power upon the energy gained in an accelerator. Neglecting anything which may happen in a bunching section the energy gained in a given accelerator will vary as the square root of the power. Thus, if available power is equally divided and fed into two similar accelerators arranged in tandem, the energy gained in either will be only $\frac{1}{\sqrt{2}}$ of that which would be gained if all the power were fed into one accelerator. Then, since the two accelerators are in tandem and their energy gains will be additive, it is obvious that the total energy will be $\sqrt{2}$ times that which could have been obtained if power had been fed to the single accelerator. This principle was used in a machine constructed for A.E.R.E. by the Mullard Research Laboratories. It consists of two accelerators fundamentally the same as the 8-MeV accelerator just described and these are each fed from the same 2-MW magnetron receiving 1 MW each. Energy of 13 to 14 MeV is attained and pulse currents of up to 40 mA (about 18 μA mean current at 350 pulses per second) are attainable.[37] After some little modification of the waveguide dimensions to give increased energy an adaptation of this design for clinical use has been installed at St. Bartholomew's Hospital (description and illustrations of this equipment appeared in ENGINEERING, vol., 178, page 502, 1954).

RADIOTHERAPY EQUIPMENT

When the first clinical equipment, that now at Hammersmith, was nearing completion, the Ministry of Health decided to install linear accelerators operating at 4 MeV in a number of radiotherapy centres in this country. As a result, two designs of accelerator have been developed by the Metropolitan-Vickers Electrical Company and the Mullard Research Laboratories, respectively. Both have been reviewed in ENGINEERING (vol. 178, page 700 (1954) and vol. 177, page 694 (1954)) and in both cases compact designs using 1-m lengths of accelerating guide have been arranged on movable mountings so as to facilitate treatment of patients. A Mullard equipment is installed at Newcastle-upon-Tyne and a further one is to be installed at Liverpool, while Metropolitan-Vickers equipments, known as Orthotrons, are at Edinburgh, Manchester and Mount Vernon, Northwood, Middlesex; other equipments are shortly to be installed in Australia. The performance of the Metropolitan-Vickers model has been given[38] as 4·0 MeV, with a mean current of up to 125 μA giving unfiltered X-ray outputs of over 300 Röntgen per minute at 1 m from the target. It is of interest to note that this represents a mean efficiency of power conversion of 25 per cent. (2 kW to 500 watts) and indeed at the expense of some reduction of energy 800 watts, giving an efficiency of 40 per cent., can be obtained. The 4-MeV equipments use radio-frequency feedback in order to have a short accelerating-tube length and were designed for a specific clinical application. When length is less important even higher efficiency can be obtained.



(a) *Field Configuration in Smooth-Wall Guide*

(b) *Field Configuration in Loaded or Corrugated Waveguide*

Fig. 9 Fields in smooth-walled and loaded wave-guides.

Turning again to American developments, the early work at Stanford was followed by the building of an accelerator (Stanford Mark 2) which was intended to be the prototype of part of a large project. This prototype equipment[39] is 14 ft. long and is powered by a single high-power klystron (10 to 20 MW); it can be maintained reliably to give 35 MeV. There is no special bunching section and the present working level is set at 10^{11} electrons per pulse by allowable radiation levels. Following this equipment Stanford have realised their real aim in the Mark 3 machine.[38] The construction of this equipment began in 1949 and the intention was to produce an energy of 1,000 MeV. It consists of a number of sections each 10 ft. long and each fed by a single high-power klystron amplifier. Thus each section is very similar to the prototype Mark 2 equipment. The total length of the equipment is 220 ft. and partial operation with the first 80 ft. was begun in 1951. Initially, the equipment did not use a special bunching section and various types have been considered during the development. The equipment has now been fitted with a bunching section of varied phase velocity similar to those used in British machines. The present performance of the machine is quoted as being 630 MeV which was obtained using 21 klystrons with approximately 9 MW peak power from each klystron. Mean current is given as 1·0 μA corresponding to 10^{11} electrons per pulse, or since pulse length is 0·3 μs a pulse current of 50 mA.

In passing, it is interesting to note that in America the techniques developed at Stanford are now being applied to clinical work much as the British developments led to X-ray therapy equipments. An equipment[40] developed by the High Voltage Engineering Corporation in collaboration with Stanford has recently been installed at the Argonne Cancer Research Hospital. Following the general Stanford high-energy practice, it is for 50 MeV, being two 8-ft. lengths of accelerator each powered by a high-power klystron. It is only required to produce a very small current since it is intended to use the electron beam directly for treatment. The energy of this equipment can be varied over a wide range, this being a property of any multiple-feed type of electron accelerator since it is possible to vary the phase relationship of the power fed to the different sections.

BRITISH AND AMERICAN CO-OPERATION

It is also of interest that after some divergence of approach British and American designers are now making full use of techniques developed on both sides of the Atlantic. For instance, it is understood[38] that the High Voltage Corporation now have in development a 6-MeV equipment intended for X-ray therapy which will be similar in some respects to the 4-MeV equipment used for this purpose in Britain. Also with the development of klystrons by the Atomic Energy Research Establishment and by the Metropolitan-Vickers Electrical Company the way is open for British designers to use multiple feeding techniques and produce high energy. An accelerator has been built by A.E.R.E. at Harwell which is similar in construction to the earlier 13 to 14-MeV machine but is fed by a klystron of the Stanford type instead of a magnetron. The power is divided, 2 MW being fed to the first 3-m length of guide while power fed to the second length which is also 3 m long may be varied over the range 0 to 8 MW, thus enabling the output energy of the equipment to be varied. Maximum energy is quoted as 34 MeV although somewhat higher values (37 MeV) can be obtained by running the klystron at higher power (12 MW). Pulse length is approximately 2 μs and recurrence rate is at present restricted to 50 pulses per second, so that the 10 μA mean current which has been obtained corresponds to a pulse current of 100 mA. A new equipment, which will be considerably more efficient and have higher power output than anything yet built, is at present being constructed by Metropolitan-Vickers and will be installed at Harwell. It will consist of six sections of accelerator each approximately 1 m long and basically similar to the Metropolitan-Vickers 4-MeV equipment. Each section will be powered by one 6-MW klystron which, having a pulse length of 2 μs and able to operate at 750 pulses per second, can provide 9 kW of mean power. The equipment is conservatively designed to give at least 25 MeV at a pulse current of 750 mA and theoretically should give pulse currents up to one ampere. It can thus be seen that an electron beam of mean power in the region of 30 kW might be expected. The machine is to be used as a neutron source by using the gamma-neutron reaction in uranium but the sectionalised arrangement provides ready-made designs for other machines of, say, 5 MeV 5 kW and so on, *pro rata*.

APPLICATIONS OF LINEAR ACCELERATORS

Most of the equipments described have been designed so that their beams may be used either directly or by means of their interaction with a

target for pure physical research. Some more utilitarian application has, however, already been mentioned in connection with radiotherapy and this is an application which is likely to extend both in the use of X-rays and in direct use of electron beams. It is interesting, however, to consider any other applications. The use of proton accelerators in any field other than pure research would at present seem unlikely. So far as the author is aware, no application has yet been made and the only possible one would seem to be for the production of short-lived isotopes or those which cannot be produced by irradiation or as a fission product in a nuclear reactor. Such a scheme is at present in preparation at the Medical Research Council at Hammersmith, but here a cyclotron will be used.[41] As regards electron accelerators there appear to be several applications especially for equipments of relatively modest energy. For radiotherapy, Van de Graaff equipments, and travelling-wave linear accelerators are already in routine use in certain hospitals. For industrial radiography similar equipment is needed and for the examination of heavy and thick objects energies of a few MeV are required along with large X-ray outputs. In a recent consideration[42] of this problem the author has concluded that the 4-MeV travelling-wave linear accelerator provides an almost ideal equipment for this purpose, providing good resolution of any flaws in the material and enabling objects of steel up to 13 in. in thickness to be dealt with in a one-hour exposure. There are two further possible applications of electron accelerators which would appear to offer great promise for the future. The sterilising action of ionising radiations has long been known, but its application on a large scale has been prevented by the inadequacy of the sources available. Now, when direct electron beams of energy sufficiently high to penetrate considerable thicknesses are available and at sufficient current to be able to treat large quantities of material the process seems extremely attractive. It is possible to treat by this method products in their final containers, i.e., after packing and since very little energy absorption is required for sterilisation there is very little heating effect so that thermally unstable products can be dealt with in this manner although normal techniques would cause their decomposition. Both Van de Graaff and travelling-wave accelerators have been used for this purpose and either provides an economic solution. It would seem likely, however, on a long-term basis where considerable penetration and very great power outputs are required that the travelling-wave accelerator would provide the better solution.[43]

It has been suggested that electronic sterilisation of pharmaceutical products is imminent and the extension to the pasteurisation of foodstuffs, etc., is a future possibility. While technically and commercially such processes are possible considerable caution is required and the applications need careful investigation for any undesirable effects. Energy in general will be too low to cause any radioactivity or nuclear changes but radiochemical effects can and do to some extent occur. While in dealing with pharmaceutical products there is little chance of these causing any trouble, they are known to cause undesirable changes of flavour in many foods and though there would seem to be little chance of any toxic effect a deterioration of nutritive value might in certain cases take place. The problems are, however, being investigated in several centres and it would seem possible that even such troubles as change of flavour might eventually be overcome. A second new application is the electron irradiation of certain plastics. It has been found that when certain polymeric materials are irradiated their structure is altered so that cross-links between the long-chain molecules are formed. This has the effect of making them resistant to solvents and stable at temperatures above their normal melting point. Thus polythene, which normally melts at 115 deg. C. can, within the limits set by oxidation, be maintained at very much higher temperatures. Much of the early work on this phenomenon was done by Charlesby at Harwell using the radiations of an atomic pile. The same effects can, however, be produced by electron bombardment and the process becomes much more controllable and for certain applications economically attractive. As for sterilisation both travelling-wave and Van de Graaff equipments are competent to deal with the problem but for the same reasons it might be expected that the former is more likely to find industrial application. The economics of this process have been examined[43] and small-scale applications may be expected in the near future.

ENGINEERING PROBLEMS

Although in reviewing the progress of linear-accelerator design there has been little opportunity to discuss the mechanical construction of such equipment, mention of the sizes and power of such devices is a clear indication of the magnitude of the engineering tasks involved. Indeed, in undertaking a large accelerator the skills of engineers in many different fields are pressed to the limit. A few examples will illustrate this point.

It is obvious that any accelerator must be maintained at a sufficiently good vacuum to prevent scattering of the particles and although this requirement is perhaps less stringent in linear accelerators than it is in orbital equipments nevertheless pressures of the order of 10^{-6} mm. of mercury are required. In certain cases, for instance in proton accelerators, this pressure has to be maintained in a tank some 40 ft. long and 4 ft. in diameter and including a large number of components all providing large areas of surface. Large vacuum pumps are required and indeed accelerator design is providing the stimulus for advanced development of vacuum techniques. In some cases mercury pumps with liquid-air cold traps are used and in others high-speed oil-diffusion pumps are employed. With these latter it has recently been found that considerable improvement can be obtained using activated-charcoal traps and this is the method which will be used both in the 50-MeV proton accelerator and the 25-MeV electron equipment at present being made for Harwell. It should be mentioned that the vacuum problem in any accelerator is made more difficult in that the presence of high electric fields causes stripping of gas from the surfaces and large amounts of gas are evolved when the equipment is first energised.

Mechanical problems play their part and it requires little imagination to see the difficulties involved in the manufacture of the outer shell of a 40-ft. cavity of a proton accelerator and the mounting of this in its vacuum tank. For electrical reasons copper must be used for the cavity, a good surface finish is required to minimise radio-frequency losses and dimensional tolerances of $\frac{1}{16}$ in. must be maintained. In fact copper sheet cannot be obtained sufficiently large to make this shell in one piece and two sheets have to be used with a circumferential copper weld which must provide a high conductivity joint. Drift tubes have to be mounted in the accelerator and dimensional tolerances both on these components and on their spacing are of the order of 0·001 in. The supports for drift tubes have some effect on the radio-frequency fields and it is desirable that they should be as thin as possible. When it is considered that these supports must provide a path for cooling water and also electrical supplies for the magnets, and further, when the weight of a drift tube is some 80 lb., it is seen that this is no easy problem.

The construction of accelerating structures for electron accelerators provides its own problems. Here dimensional tolerances are of the order of 0·0001 in. and various different techniques have been used. A very good account of the technique used in the Stanford projects has been given by Chorodow *et al.*[33] who have used a process of shrink fitting. British techniques have used brazing and clamping schemes[26, 38]. Large mean powers are involved in some accelerator projects and this involves a cooling problem which is made more severe because the temperature of the structure must be maintained constant within a few degrees.

Radio-engineering problems are legion in any indirect linear accelerator programme. The demand for high powers has led to valve development intended immediately for accelerator application but this will obviously influence other applications. The Stanford development of klystrons is a remarkable achievement and this is now being followed by the development of similar valves of somewhat lower peak power but high mean power at A.E.R.E. and Metropolitan-Vickers. These provide the power source for future high-power electron accelerators. For proton accelerators most work so far has been carried out with valves developed for other purposes but A.E.R.E. are now developing high-power triodes for 200 Mc/s operation for the 50-MeV accelerator. The circuits used with these high-power valves and the modulators for driving them can be considered as an extension of radar techniques and again the skill of the designer is pressed to the limit. Problems are raised even in the power supply to such equipments since the power taken from the mains may be as high as several hundred kilowatts and thus represents a sizable undertaking from the point of view of power engineering, and since incorrect operation can cause considerable damage to the equipment the provision of protective devices is of the greatest importance.

The safety of operating personnel has to be ensured and interlocks to prevent danger from high voltages and radiation must be included in a scheme which, while ideally being fool-proof, should not make the investigation of fault conditions too cumbersome. In passing it should be noted that the radiation output is usually extremely high, thus requiring considerable amounts of protection and the buildings to house accelerators must be regarded as major undertakings in themselves.

A difficulty not always appreciated is that, particularly in a long accelerator, the alignment of the particle path in a straight line may provide great difficulty. Not only are advanced optical methods required for the initial setting of the equipment but reference marks must be made available so that the equipment can be checked periodically for any settling. The mounting of the equipment to minimise settling involves the civil engineer in deciding the construction of the foundation and indeed may involve the geologist in the choice of site.

When small accelerators are used for therapy or industrial radiography mechanical problems of a rather different nature are introduced since for these applications it is necessary for the accelerator to be moved at will to provide beams in the most convenient direction.

CONCLUSIONS

In reviewing the development of linear accelerators its has been shown how from early apparatus giving energies of a few keV progress has been made to the present very large equipments providing protons up to 50 MeV and electrons up to almost one GeV. Direct acceleration has been shown to be limited to a

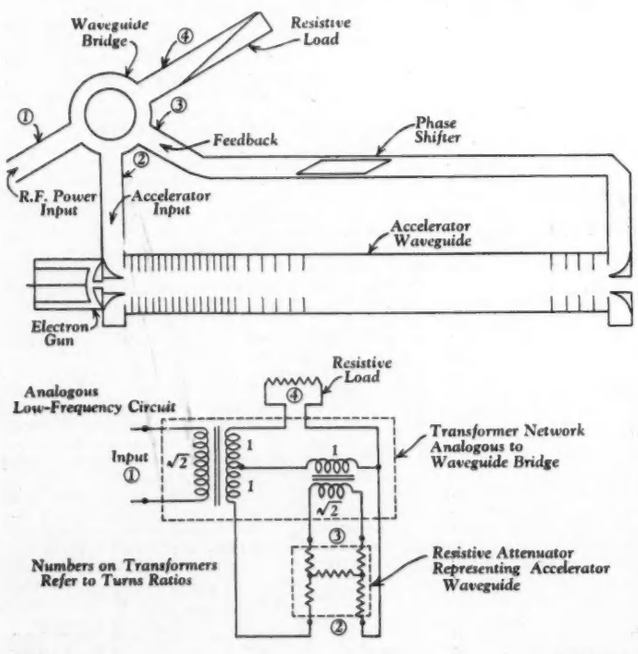


Fig. 10 Principle of radio-frequency feedback. Radio-frequency power is fed back through the waveguide bridge circuit and combined with the incoming power to give increased power flux in the accelerator.

few MeV energy but nevertheless, particularly in the form of the Van de Graaff generator, it finds considerable application. For higher energy indirect acceleration is used and here energy would seem to be virtually unlimited and in addition large current and hence power can be provided. Since radiation loss which provides a limitation in orbital equipment plays a negligible part when particles are linearly accelerated there is no theoretical upper limit to energy, and it would seem that the limit is only introduced by economics and by the availability of a sufficiently large number of radio-frequency power sources. Extension beyond the energies yet attained both for protons and electrons is clearly obvious. The Stanford project has been limited only by the difficulties associated with the production and maintenance of klystrons and it is understood that they are about to embark on an extension beyond one GeV. As regards protons a design study has been undertaken in connection with the 50-MeV accelerator for A.E.R.E. and both the basic physics and many engineering problems considered for extension to higher energy. It has been shown that it would be technically feasible by extending to an overall length of 900 ft. to produce one μA mean current of protons at an energy of 600 MeV.

It must not be forgotten that future developments may provide other accelerating structures and indeed modified methods of aceleration may arise. As indication of this we may quote the dielectric loaded guide for electron acceleration in which the familiar metallic irises are replaced by similar discs of material of high dielectric constant. This scheme was suggested by Harvie[44] in 1948 as providing a structure of very low loss and although there are certain difficulties he later operated an equipment using such an arrangement. As an example of a different method of acceleration note may be taken of a scheme suggested by Alfven and Wernholm[45] in which positive ions may be accelerated by being attracted along behind bunches of electrons which are arranged to travel at an appropriate velocity.

For the highest energy machines comparison with orbital equipments is inevitable. It can be said that in general the linear device is usually capable of higher currents but whether this advantage can be justified on economic grounds depends partly on the actual application and also, of course, on the relative state of development of both types of machine at the moment when the decision has to be made. It should be remembered that development is continuous in both fields and the relative merits of the types of equipment can be expected to change from time to time. For electron accelerators of a few MeV energy but considerable power output the travelling-wave accelerator appears to be an almost ideal equipment and the application of this along with the Van de Graaff accelerator to new industrial processes is a matter which can be expected to produce considerable interest in the next few years.

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THE SCIENTIFIC DEVELOPMENT OF MODERN LOCOMOTIVE DESIGN*

FROM STEAM TO DIESEL AND GAS TURBINE

By J. S. Tritton, P.P.I.LOCO.E., *and J. J. C. Paterson*, C.I.E.

In this paper the authors review the development of Diesel and gas-turbine locomotives in comparison with modern steam locomotive practice. They consider not only thermal efficiencies but also the efficiency of each type from the using railway's point of view.

STEAM LOCOMOTIVES

A cheap and efficient rail transport system is absolutely essential for the well-being of all countries and, notwithstanding the fact that road transport has largely superseded that by rail for some classes of traffic, the railways must continue to function, particularly for the transport of heavy commodities. The cost of this transport is a very important factor in the cost of manufacture and bears both directly and indirectly upon the cost of living. In the early days of railways, haulage was by steam locomotives and no alternative means of power were available. This resulted in the development of the steam locomotive attaining a high degree of reliability and efficiency, but it must be admitted that development at that time was obtained largely by practical trial and patient study of operation in service. The urge for still greater efficiency, however, resulted in the greater application of scientific principles in design, and specially designed testing plants were installed in several countries in which locomotives could be tested under controlled conditions, thus eliminating the variables inseparable from dynamometer-car trials on the track. The testing plants belonging to the British Railways are situated at Rugby and Swindon. That at Rugby was described in detail in ENGINEERING, vol. 166, pages 462 and 487 (1948).

TESTING PLANTS

The locomotive being tested is operated under its own steam and the wheels are supported on rollers, the position of which can be adjusted to suit the wheel spacing of each locomotive. The rollers are connected to water brakes which absorb the energy by churning a mass of water, the resistance of the brake increasing as the amount of water in the brake increases. Each brake can be independently controlled. The locomotive is held in position by a drawbar which replaces the normal intermediate drawgear between engine and tender. This drawbar is connected to a hydraulic dynamometer through a spring and measures the pull which the locomotive exerts. Equipment is provided for measuring and controlling the steam flow and for measuring the pressure, velocity of draughts and temperature at points which affect the combustion and the steaming of the engine. At Rugby the steam cylinders are indicated by means of a Farnboro-type indicator which is an instrument of the balanced-pressure type, recording on a crank-angle basis and producing a complete indicator diagram in one or two hundred revolutions.

The principle of this indicator is that the diaphragms of the pressure elements separate the steam in the cylinders from gas under a pressure that can be varied slowly at will between atmospheric pressure and a pressure slightly higher than the boiler pressure of the locomotive on test. The steam pressure will, in general, rise above and fall below the gas pressure once in each cycle, causing a very small movement of the diaphragm to make or break an electric contact. By electronic means the impulse is amplified and a spark is produced from a pointer, the position of which depends on the gas pressure, this spark perforating a paper on the indicator drum, which is rotated by the wheels of the locomotive through a return crank.

The diagrams thus produced have to be converted from a basis of angle of rotation to one of piston stroke to obtain the value of the mean effective pressure and so the indicated horse-power. An instrument designed at Rugby enables this to be done quickly, usually before the test has been completed.

The coal for firing the locomotive is taken from a small hopper, which is carried on a weighing machine and is replenished from the coal store by means of an overhead runway. The water for the locomotive boiler is taken through meters from a calibrated tank, which can also be refilled from two further tanks of known capacity.

The methods used at Rugby are essentially the same as those used at the British Railways Swindon test plant, the differences being due to the use of different equipment and not to any difference in approach to the fundamental problems. Certain practices (and the equipment that make them possible) originated at Swindon, which is the older establishment. The testing plants also cover dynamometer-car trials which

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are essential for checking the test-bed results with operating conditions on the track.

The essential objects of all locomotive testing are to establish the performance characteristics of any given locomotive design; to establish the capacity of locomotives of any class for performing their duties as motive power units; and to relate any particular working to the corresponding consumption of fuel and water. Information on the most economical loads and speeds is also supplied to the operating departments to enable the locomotives to be used to the best advantage in service.

An interesting contribution to the advancement of science in the locomotive field has been made by the Swindon Locomotive Testing Office in the cost of energy diagram reproduced in Fig. 1. The significant factor in this diagram is that traffic capacity is given in ton-miles per hour, whereas the majority of railway statistics are based on ton-miles hauled without reference to speed. The diagram is of special importance at the present time because it shows the effect of speed on the cost of rail transport. Its implications, therefore, merit the careful consideration of those who so often nowadays call for higher speeds on our railways. For instance, the chart shows that a " King " Class locomotive is working at its best efficiency of 7 per cent. when hauling loads of 540 to 640 tons at a little over 50 m.p.h. The cost is then 0·05*d.* per ton-mile. If, however, the same total tonnage is taken the same distance in lighter, faster trains, say, 500-ton trains at 60 m.p.h., the efficiency drops to less than 6 per cent. and the cost rises to 0·075*d.* per ton-mile—an increase of 50 per cent.

The diagram, it should be noted, is based on non-stop journeys of 173·5 miles on an undulating route but is generally applicable to other routes providing the average speed is reckoned over a long distance. Mean thermal efficiency is referred to the actual work done in displacing the trailing load. In the cost of energy, lighting-up and stand-by coal have not been included.

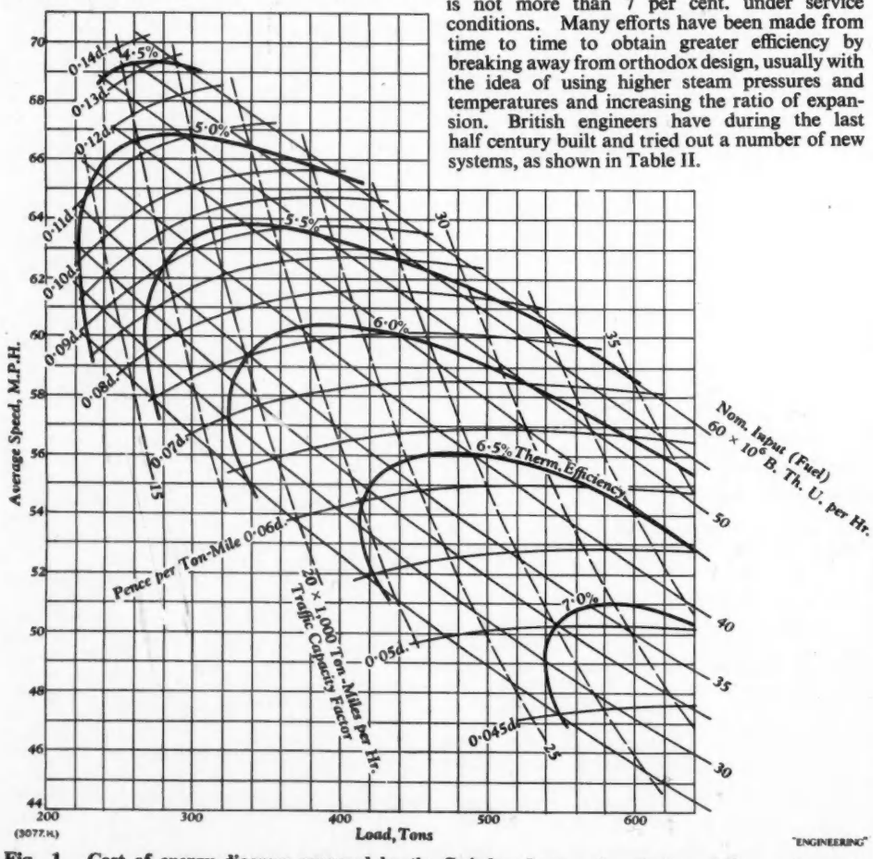


Fig. 1 Cost of energy diagram prepared by the Swindon Locomotive Testing Office. It reveals the increased cost of higher speeds on the railways.

Fuel price is based on 43·25*d.* per 10^6 B.Th.U., made up of: pithead price 68·5 per cent., freight charges 29·5 per cent., handling appliances 0·3 per cent., and wages 1·7 per cent. The input (nominal working rate) is connected with steam rate (cylinder feed) as shown in Table I.

TABLE I.—*Showing Fuel Input and Steam Rate*

Input (B.Th.U. per hr.)	Steam rate (lb. per hr.)
27·5 × 10^6	17,700
30·0	18,950
32·5	20,100
35·0	21,300
40·0	23,500
45·0	25,450
50·0	27,200
55·0	28,850
60·0	30,250

The information thus made available is used for the correct allocation of locomotives to the various tasks required for the operation of a railway and for the correct loading and timing of trains to permit the locomotives to be used within that range of working conditions in which they can work with reliability and economy. The test results are of course used as a basis for improvements of design, which can greatly increase the effectiveness of the locomotive as a motive power unit, or as data for the design of better locomotives in the future. As an instance, the tests on the V2 Class locomotive may be quoted by which the steaming capacity was increased from 14,000 to 30,000 lb. per hour. The research and development which have been carried out have resulted in the modern steam locomotive being an efficient and reliable machine *within its limitations.*

THERMAL EFFICIENCIES

Unfortunately, the thermal cycle which is employed in the steam locomotive must of necessity impose limitations and though modern designs can now operate at an overall thermal efficiency of 10 per cent. the average thermal efficiency of the majority of steam locomotives is not more than 7 per cent. under service conditions. Many efforts have been made from time to time to obtain greater efficiency by breaking away from orthodox design, usually with the idea of using higher steam pressures and temperatures and increasing the ratio of expansion. British engineers have during the last half century built and tried out a number of new systems, as shown in Table II.

TABLE II. *Experimental Locomotives of Unorthodox Type Produced in Great Britain*

1908	Midland Railway ..	Paget's eight-cylinder single-acting 2-6-2 locomotive, with sleeve valves
1910	North British Locomotive Company	" Reid-Ramsay " turbo-electric condensing locomotive
1913	North Eastern Railway	4-6-0 tender engine rebuilt with Stumpf uniflow cylinders. (A further locomotive of 4-4-2 type was similarly rebuilt in 1919)
1922	Ramsay/Armstrong Whitworth	" Ramsay " turbo-electric condensing locomotive 2-6-0 + 0-6-2
1926	Beyer Peacock ..	" Ljungstrom " turbo-condensing locomotive
1928	Kitson's	" Kitson-Still " Diesel steam 2-6-2 tank locomotive
1929	L.N.E.R./Yarrow ..	Four-cylinder high-pressure compound 4-6-4 locomotive No. 10,000, with Yarrow water-tube boiler
1930	L.M.S./North British Locomotive Co.	Three-cylinder high-pressure 4-6-0 locomotive No. 6,399 " Fury," with Schmidt dual-circuit water-tube boiler
1930	S.R.	2-6-0 tender engine, with compression condensing apparatus (Anderson's patents)
1935	L.M.S.	4-6-2 non-condensing turbine locomotive No. 6202
1949	British Railways, Southern Region	Bulleid's six-cylinder double-bogie tank locomotive, of " Leader " class, with sleeve valves

It may be asked why, since these numerous and expensive efforts to raise the efficiency of the steam locomotive have proved so disappointing, the orthodox type has survived so long. The answer is probably its low initial cost, its simplicity and its ability to withstand overloading and neglect in unskilled hands to a remarkable degree.

ALTERNATIVES TO STEAM

For some time the locomotive designer had to be satisfied with these results, but of recent years science has made rapid strides in developing alternative means of power, and it is the purpose of this paper to describe very briefly and with as few technicalities as possible the trend of existing locomotive development and the possibilities which now lie before the railway engineer for railway projects for which complete electrification would not be justified. The scope of this paper is only sufficient to deal with main-line and shunting locomotives, and consideration of railcars and multiple Diesel-engined stock is excluded. Reference is largely to experience in the United States because in no other country have either Diesel locomotives or gas-turbine designs been so widely adopted. Unfortunately, space limitations do not permit of a detailed description of equipment and design.

INTRODUCTION OF THE DIESEL

Apart from complete electrification the greatest challenge to steam in railway operation comes at present from the internal-combustion engine. Since 1920 consistent improvements in design have reduced the weight of Diesel designs from 200 lb. per horse-power to the 10 lb. per horse-power we know in the power units of to-day—truly a remarkable technical achievement. To America must go the credit for putting the Diesel engine into effective railroad service. During the depression after the first World War the American railways faced a need for drastic economy by all possible means. They were losing traffic to the roads and the Diesel engine, in spite of its high first cost, offered a startling development in railway transportation which appealed to the American mentality.

In the late 1930's the tide turned. American locomotive builders found their orders for steam locomotives dwindling while the Diesel shops could not expand fast enough to keep pace with the demand. By the end of 1947, American builders had turned out over 5,600 Diesel locomotives, about one-third of which were for main-line services. Such a revolution in locomotive demand does not just " happen "; it could only be based on financial justification. The Diesel had shown that it could haul heavier loads faster and more cheaply than its older rival.

These particulars of American practice are quoted because America is by far the largest user of Diesel locomotives, and the figures

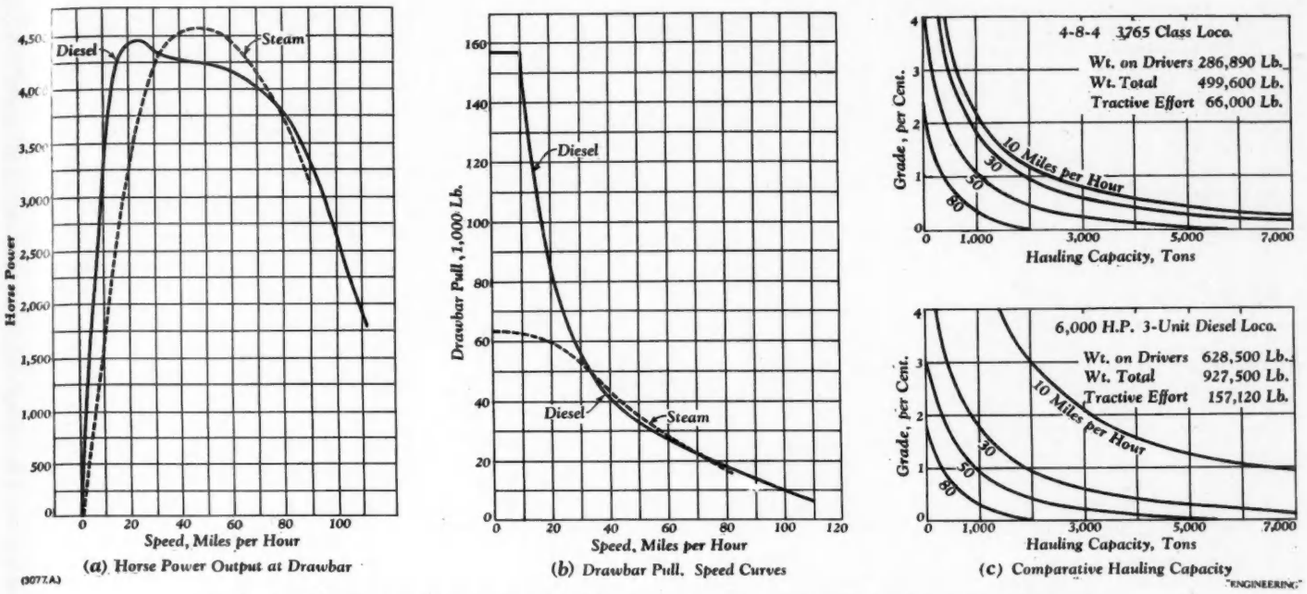


Fig. 2 Performance comparison of equivalent steam and Diesel locomotives of the Santa Fe Railway.

collated by the American Inter-State Commerce Commission are the most reliable guide that we have available.

Comparison with Steam.—One of the major problems is to find a yardstick by which to compare the Diesel with the steam locomotive. Obviously, no single formula will give the answer, so opinion must be based on performance and cost. If these headings are sub-divided, the comparison can include rating, efficiency and utilisation. A comparison of capital and maintenance costs will then complete the general picture.

Performance.—In the early days much was made of the spectacular cuts in running time of long-distance trains. It was indeed a fine achievement to introduce the Union Pacific schedule of 2,200 miles in under 40 hours, a saving of practically one business day on the previous timing. Such runs are now commonplace in the United States. It should be noted, however, that quite a big proportion of the time saved is not by greatly increased speed but by cutting out and shortening many of the stops which are essential for the steam locomotive.

SHUNTING PURPOSES

For shunting purposes the Diesel-electric locomotive is, admittedly, the most effective type and is being widely adopted in all countries. As long ago as 1947 a comparison based on a year's actual results in service on one railroad in the United States is as follows: a steam locomotive burns 1,100-1,200 lb. of coal per hour at 4·18 dols. per ton; a Diesel locomotive burns 13 gallons of fuel per hour at 6 cents per gallon; the Diesel does as much work in 8 hours as the steam in 24; the all-in costs were 5·30 dols. per hour for Diesel against 9·09 dols. for steam. Admittedly, these figures reflect the relative costs of coal and Diesel oil to that administration at that time but wide experience has shown that savings of that order can be attained when the changeover from steam to Diesel is made under comparable conditions.

Rating.—The rating of an engine is its capacity for work and we should, therefore, be able to find a common horse-power basis on which to compare steam and Diesel units. Actually, the comparison is an extremely difficult one to evaluate, taking into consideration all the variables concerned. Steam locomotives are generally rated on the basis of tractive effort, grate area and heating surface although, as we have seen on the test plants, the cylinder or drawbar horse-power can be readily ascertained under any given conditions. By comparison, the power of Diesel locomotives is usually based on the horse-power of the Diesel power unit and this, in turn, varies with the rating assigned by the makers to any engine for a particular service.

On the test bench very high maximum outputs can be obtained for short periods, but experience has proved that if such values are taken as the engine rating for service conditions, then the cost of maintenance mounts rapidly, periods between overhauls become too short and the reliability and the life of the engine are seriously affected. It is, therefore, agreed by both users and builders that this maximum test-bed horse-power bears little relation to the continuous rating on which an engine is to be used under service conditions, but the standardising of the continuous rating for traction purposes is at the present time quite controversial. The matter has been considered by the International Union of Railways on the Continent and the British Standards Institution, but so far no generally acceptable proposals have been advanced.

There are also further factors to consider in a comparison. The output of the coal-fired steam locomotive is subject to greater variation in the heating value of the fuel than in the case of a Diesel employing oil, and hand firing introduces the reliability or otherwise of the human element. Allowances must also be made for auxiliaries, particularly in the case of Diesel locomotives. The useful work performed by the locomotive is the drawbar horse-power and this is probably the best basis for scientific comparison, but for various reasons including the allowances to be made for auxiliaries, train heating, air conditioning, etc., it is not convenient or suitable for operational statistics.

OPTIMUM RATING

As previously stated, rating and de-rating are intimately connected with maintenance cost and reliability. Experience in service has shown that these vary almost directly as the rate of fuel consumption. It is fairly simple to find the optimum loading or "rating" for any engine after it has been in service for some time, i.e., long enough to determine the most economical periods between top overhauls and major overhauls. The Diesel locomotive designer can then arrange the setting of the fuel pumps and electrical control gear so that the service rating cannot be exceeded; in other words, so that the engine cannot be loaded to a greater extent even on the "overload" notch, which is usually 10 per cent. above the permitted full-load rating. The steam locomotive has no such protection but, conversely, will reward good enginemanship by low maintenance and fuel consumption.

Another important factor which enters into the rating of a Diesel-electric locomotive is the ratio of traction-motor rating to Diesel output. One of the major claims put forward for the Diesel-electric locomotive is that it will start and accelerate heavier loads than the equivalent steam locomotive. This advantage is given by the infinitely-variable gear ratio of electric transmission. There is, however, a limit to this feature in the overheating of traction motors. The temperature rise of traction motors is directly related to tractive effort; consequently, overloading can only be sustained for limited periods. The effect of this in practice is to limit train loads not only to the steepness of the grade but to the length of it. This was demonstrated in the early days by failures when small Diesel-electric shunting locomotives were used for pushing heavy trains at very slow speeds over the hump in a hump shunting yard.

The same conditions apply in main-line service where locomotives are called on to handle trains at loads and speeds unsuited to their transmission ratios. In the past there has been a tendency on the part of the purchasers to specify a higher maximum speed than is required in normal everyday service with the idea of having a margin of safety. This may prove an expensive precaution. If the traction motors are designed and geared for a maximum speed of say 110 m.p.h., as is quite usual for high-speed operation, they cannot be expected to handle heavy freight loads at 15 to 20 m.p.h. If, on the other hand, the design range of speed is reduced so that full-load conditions can be sustained, say, from 15 m.p.h. to 80 m.p.h., the locomotive will take care of a wider range of both freight and passenger loads.

Fig. 2 gives a comparison of the tractive effort and drawbar pull of a Diesel and a steam locomotive of similar horse-power. The first diagram shows the horse-power plotted against speed for a 6,000-h.p. passenger Diesel and for a 4-8-4 steam locomotive. These are both Santa Fe locomotives. Their horse-power output is practically the same, but the drawbar horse-power curves are very different. The second diagram shows that the Diesel tractive effort can go right up to the limit of adhesion, and considerably exceed that of the steam locomotive, provided that the traction motors are not over-run for a longer time than their rating will stand in that period. The effect is shown in the curves of the third figure which shows the hauling capacity in tons plotted against the grade in percentage. It will be seen that the Diesel has a much greater hauling capacity at the low speeds of 10 and 30 m.p.h., but that at the high speeds, 50 and

TABLE III.—Unit Operating Costs in the U.S.A., Cents per Locomotive Mile (Main-Line Service)

Railroad Reference ..	1	2	3	4	5	6	7	8
No. of steam locomotives	169	156	269	20	312	17	71	159
No. of Diesel locomotives	49	84	128	8	132	10	14	75
No. of Diesel locomotive units ..	109	130	292	16	184	18	23	172
Engine miles, steam (millions) ..	3·35	5·58	7·62	1·28	9·56	0·72	0·68	1·30
Engine miles, Diesel (millions) ..	2·91	5·30	5·67	1·28	8·72	0·72	0·59	0·92
Coal costs per 2,000 lb. (dols.) ..	6·39	5·20	3·17	6·07	—	—	8·66	—
Diesel fuel per U.S. gal. (cents) ..	6	6	6	7¼	4¼	6¼	8	6¼
Steam locomotive costs (cents per mile):—								
Repairs	45	34	78	48	30	45	43	51
Enginemen	29	26	23	29	22	26	28	24
Fuel	58	47	57	57	34	52	82	79
Water	3	3	3	—	3	—	2	4
Lubricant	3	2	1	—	1	—	1	3
Other supplies	1	1	1	4	1	5	1	5
Enginehouse	25	7	16	14	5	12	6	16
Total (dols.)	1·64	1·20	1·79	1·52	0·96	1·40	1·63	1·82
Locomotive tractive effort (lb.) (average)	80,000	85,000	110,000	42,000	60,000	60,000	60,000	100,000
Diesel locomotive costs (cents per mile):—								
Repairs	31	30	31	20	30	30	30	35
Enginemen	30	24	25	20	21	19	24	26
Fuel	32	33	40	20	21	33	48	39
Water	—	—	—	—	—	—	—	—
Lubricant	4	4	7	2	4	4	5	7
Other supplies	1	1	1	1	1	1	1	1
Enginehouse	1	2	2	3	1	2	1	4
Total (dols.)	0·99	0·94	1·06	0·66	0·78	0·89	1·09	1·12
Locomotive h.p.	6,000	4,500	6,000	3,000	4,500	4,500	4,500	6,000
Percentage return on investment ..	18·9	17·2	15·8	42·8	16·7	17·6	25	12
Ratio costs Diesel/steam per loco. mile	0·60	0·78	0·60	0·40	0·81	0·64	0·67	0·62

80 m.p.h., there is very little difference. The steam locomotive is actually a little better at 50 m.p.h.

An interesting comparison of the hauling characteristics of steam and Diesel locomotives is given in Fig. 3 and is taken from Kiefer's paper on Railway Power Plant, contributed to the recent Centenary Meeting of the Institution of Mechanical Engineers. The S-1 type steam locomotive is a 4-8-4 passenger or freight design of 6,600 h.p. and the J-3 is a 4-6-2 passenger locomotive of 4,700 h.p. The Diesel locomotives exert 6,000 h.p. and 4,000 h.p. The results were obtained on the New York Central Railroad.

Availability. The first cost of a Diesel-electric locomotive is greater than that of a steam locomotive and therefore involves higher standing charges for interest and depreciation. In addition, the life of a large portion of the equipment is less. These factors tend to increase the total operating cost per mile, and notwithstanding a possible saving on fuel cost, the only way in which the additional charges can be completely offset is for the Diesel to have a much greater availability for service and for the traffic conditions to show a greater average utilisation mileage per day. If adequate arrangements are made for satisfactory maintenance and servicing, experience has shown that the Diesel locomotive can comply with these requirements and availability figures of over 90 per cent. are quoted. The greater availability of the Diesel is particularly well marked in the case of shunting locomotives, but the operating department may have difficulty in taking full advantage of the greater availability when employed on main line services.

Reliability and Servicing.—Availability is largely, but not entirely, dependent on reliability, and provided the Diesel power unit is adequately de-rated the reliability is of a high order. Servicing, with the provision of proper equipment and facilities for the purpose, is also easier than for steam locomotives, particularly if bad boiler waters are involved. In American practice a 6,000-h.p. Diesel can be serviced in 6 to 10 hours for a 4,800 miles round trip with 21 changes of crew. With regard to reliability, some extraordinary cases can be quoted. Three 5,400-h.p. Diesel freight locomotives on the B. and O. Railroad in the United States carried out their regular scheduled working day for two years without a failure. One high-speed passenger locomotive worked its train 1,000 miles a day for five years and three months, over a million miles, without missing a trip or breaking down. Admittedly, average reliability figures for a number of Diesels would be lower. A census of average reliability and utilisation for three groups of locomotives with an average age per group of 3·5, 2·5 and 5·0 years showed an availability of 77 per cent., 85 per cent. and 93 per cent., respectively, but the percentages of utilisation in hours worked was only 52·5 per cent., 63·2 per cent. and 82·8 per cent.

ADVANTAGES OF DIESEL

Operating Advantages.—Diesel-electric traction offers the following operating advantages over steam which cannot be readily assessed in financial terms:—

(1) Diesel-electric traction makes possible a dual-purpose locomotive over a wider range of passenger and freight working.

(2) Electrical braking on the locomotive is possible.

(3) Elimination of service halts for water, coaling, cleaning fire, etc.

(4) Elimination of ash disposal.

(5) No smoke, resulting in cleaner train operation.

(6) No sparks and, therefore, redueed fire hazard.

(7) No reciprocating weight on the driving axles and, therefore, no hammer blow, resulting in higher permissible axle load.

(8) An even driving torque which reduces wheel-slip to a minimum.

(9) Shorter rigid wheelbase offered by locomotives of the double-bogie type.

(10) Better power-weight ratio.

(11) For a comparable power-weight ratio Diesel-electric locomotives give better acceleration, making better timing schedules possible.

(12) Less frequent and shorter periodical examinations.

(13) Immediate availability of full power compared with the 4 to 6 hours required for steaming up.

(14) Multiple-unit control offers a saving in train crews.

Comparison of Capital Cost.—Whereas before the war the capital cost of Diesel-electric locomotives was some three times that of the equivalent steam, it is now claimed in the United States that the ratio of cost for standard designs is from one to one and a half times that of steam. This low ratio, however, is not applicable to production in other countries and, in many cases, the standard United States designs are not suitable for adoption outside that country. The builders of Diesel locomotives in the United States soon appreciated that if their product was to be sold at competitive prices they would have to adopt mass production methods. These, in turn, demanded rigid standardisation, and certain unit sizes were decided on after careful study. This resulted in units of 1,000, 1,350, 1,500 and 2,000 h.p. which can be coupled together to give any combination of speed and tractive effort required in one locomotive. This wide range of power unit utilises only one size of bore and stroke throughout.

Operating Cost.—It is difficult to obtain comparative operating costs for a large number of Diesels under general service conditions. There is considerable lack of uniformity in the method of preparing the costs and the inclusion of certain factors. In addition, the conditions vary so largely on the various railways. For Diesels operating in quantity in general services it is quite misleading to base results on figures derived solely from consideration of a few Diesels operating on selected schedules. Table III has been worked out for conditions in the United States on a wide variation of service conditions. It covers a large number of both steam and Diesel locomotives and the figures have been compiled for many millions of miles of running. The relative costs of coal and Diesel fuel are given so that those who are interested can translate the relative costs to meet their own conditions. Unfortunately, the translation cannot be applied to the cost of labour except in a very general way. To obtain a particular ratio of labour costs it would, of course, be necessary to assess the man-hours for each class of labour with its relative rate of pay.

The figures do not include the cost for administration and ancillary purposes nor, unfortunately, do they include the all-important charges for interest and depreciation on the capital cost. If the latter were taken into account it could make an appreciable difference on the overall cost. Some idea of the overall financial comparison is, however, given by the figures showing the percentage return on investment. It will be seen that these vary widely from 15·8 per cent. to 42·8 per cent. In the case of shunting locomotives, cases have occurred under favourable conditions in which the additional cost of Diesel designs have been offset by more economical operation in three to five years.

GAS-TURBINE LOCOMOTIVES

Gas turbines employing oil as fuel have made considerable advance in design and performance and are now a practical proposition for many power purposes. Approximately 30 to 40 locomotives so fitted have recently been placed in service. The majority of these are in the United

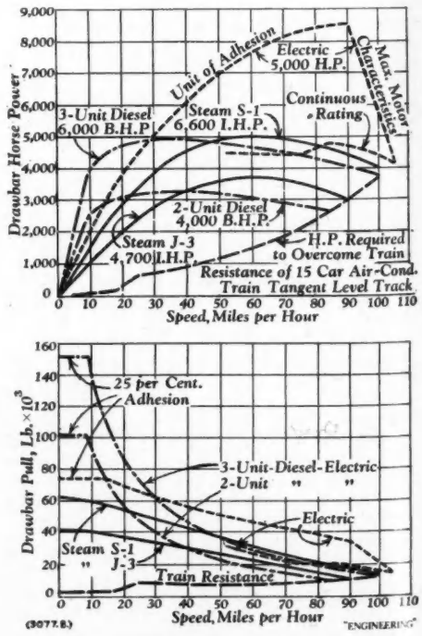


Fig. 3 Characteristic curves of steam, electric and Diesel-electric passenger locomotives.

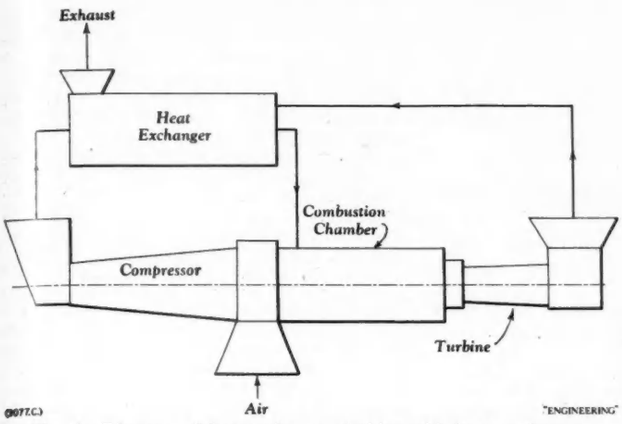


Fig. 4 Diagram of locomotive gas turbine with heat exchanger.

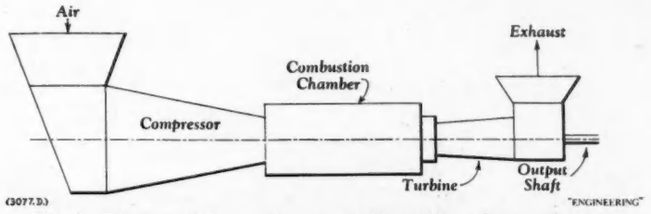


Fig. 5 Diagram of locomotive gas turbine without heat exchanger.

States although the first locomotive to operate successfully was produced in Switzerland and has now become the acknowledged pioneer of gas-turbine locomotive design. In Great Britain two locomotives are running, one of which is a development of the Swiss prototype.

The cycle and arrangements of gas-turbine equipment on a locomotive can vary considerably. A brief general appreciation of the main features can be obtained from the diagrams in Figs. 4 and 5. In the cycle shown in Fig. 4, regeneration through a heat exchanger is employed. Variations in the above arrangements can be adopted in which a separate power turbine is provided apart from that driving the compressor, but the tendency is towards simplicity with the units grouped on one shaft.

The best appreciation of a gas-turbine locomotive is obtained by briefly describing an actual design, and for this purpose the Union Pacific oil-fired locomotive is selected because it is the latest to be placed in service and more locomotives are operating to this design than to any other. It must not, however, be inferred that it is necessarily superior to either the Swiss or British locomotives.

America's first gas-turbine locomotive made its début in November, 1948, and after initial track tests went into service successively with the Pennsylvania, Nickel Plate and Union Pacific Railroads. While in the hands of the Union Pacific, this 4,800-h.p. prototype was used for hauling freight, continuing in that duty from August, 1949 to March, 1951. Satisfactory experience with the locomotive induced the railroad to order ten more of similar design. The first of this batch went into service in January, 1952, and has since covered over 290,000 miles and completed some 12,300 hours operation. Early in 1953, a further 15 locomotives of slightly improved design were ordered and the last of these was delivered at the end of 1954. Some operating figures have been made available and up to the end of September last, the 24 locomotives already delivered had covered 2,574,000 miles and had accumulated some 105,750 turbine running hours.

The Union Pacific railroad system includes a bottleneck section, where the traffic density is particularly heavy and which traverses mountainous country, including altitudes between 4,300 ft. and 8,013 ft. This section was chosen as the testing ground for the gas-turbine fleet. It is 482 miles long and runs between Ogden and Cheyenne with no gradient steeper than 1 in 125. The climate varies between a dry heat in summer to a bitter cold in winter; the region experiences high winds. The loss of performance expected due to the rarefied atmosphere and the heat in summer is compensated, to a certain extent, by the intensely cold air encountered during the winter months. This combination of weather conditions produces the longest period of dry rail experienced on the North American continent; this is advantageous to a gas-turbine locomotive, which is relatively light in total weight despite its heavy axle-loading.

The layout of the latest locomotive is shown in Fig. 6. A double-bottom tank forms the basis for the frame, and extends practically the whole length of the vehicle. The frame is carried on four, twin-axle, swivelling power bogies, each axle being driven by a 550-h.p. 900-volt direct-current motor driving through a reduction gear and giving a maximum speed of 65 m.p.h. The tank is divided into compartments for turbine fuel, Diesel fuel and water. Turbine fuel is kept at a constant temperature of 80 deg. C. (175 deg. F.) by steam pipes from the train-heating boiler. The top surface of the tank supports the gas-turbo-generator set, the entire auxiliary equipment and the general framework. Power for the eight traction motors is supplied by four 1,125-h.p. 900-volt direct-current generators driven from the turbine shaft through a 4·19 : 1 reduction gearbox. One of the four generators is provided with a motor winding for use in motoring the turbine (using current from the auxiliary Diesel) during starting operations. Shaft extensions from the two aft generators are directly coupled to two 150-kVA three-phase alternators for supplying current to the auxiliaries.

The gas-turbine power unit is a simple open-cycle, single-shaft design with a 15-stage axial compressor, six straight-through combustion chambers and a two-stage axial turbine. The turbo-compressor shaft revolves at 6,900 r.p.m. and produces 4,500 brake horse-power of useful output at 1,500 ft. altitude and 27 deg. C. (80 deg. F.) ambient temperature. Under full-load conditions, T max. is 704 deg. C. (1,300 deg. F.), pressure ratio approximately 5·4 to 1 and maximum air flow 80,000 cub. ft. per minute at N.T.P. The power unit alone measures 20 ft. overall length and weighs 15 tons. This gives a power/weight ratio of approximately 7·5 lb. per horse-power. The arrangement of the compressor-turbine unit is shown in Fig. 7. Air is admitted to the compressor at A and then passes to multiple combustion chambers B. It then enters the power turbine C which drives both the compressor and the generators and then escapes at the exhaust outlet D. The output shaft to the generators is at E. The unit uses heavy residual oil fuel, but Diesel fuel is employed for starting.

In addition to the air brakes, dynamic braking is provided for use in coasting downhill. This system serves the double purpose of saving wear and tear on the wheel brakes and of allowing the gas turbine to be shut down, thus saving the heavy fuel consumption characteristic of the turbine at idling conditions; fuel consumption when idling is no less than 60 per cent. of the full-load consumption. With the gas turbine shut down, the Diesel set supplies all necessary power requirements for the locomotive.

The set supplies sufficient power, in addition to operating all auxiliaries, to energise two of the traction motors for the purpose of moving the locomotive in marshalling yards, and even shunting a few trucks. This results

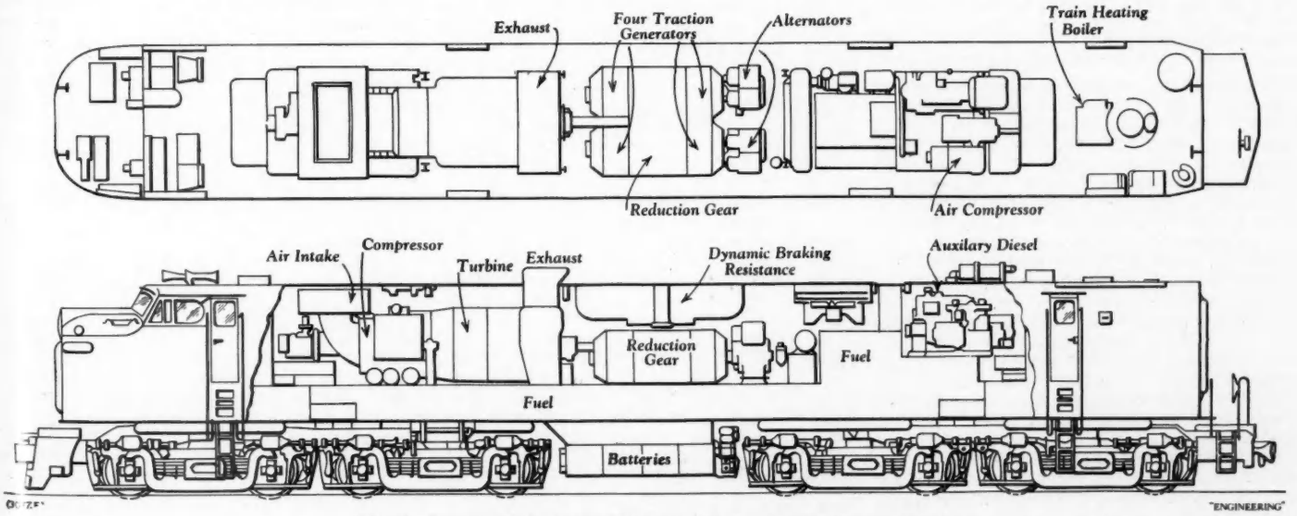


Fig. 6 Layout of the latest Union Pacific gas-turbine locomotive.

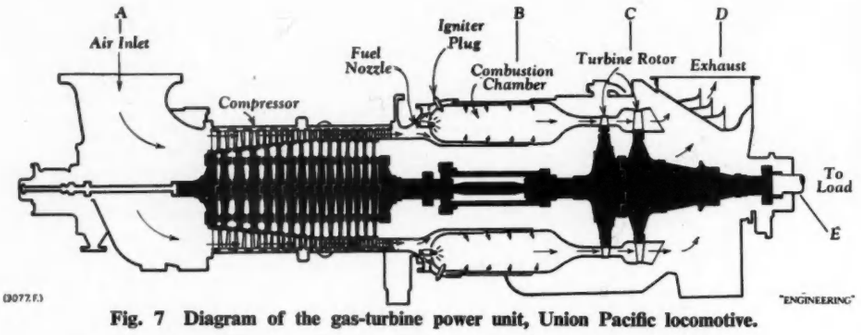


Fig. 7 Diagram of the gas-turbine power unit, Union Pacific locomotive.

in a big fuel saving in the gas turbine, which would be mostly idling in such circumstances. At the extreme rear of the locomotive a steam generator is housed capable of supplying 800 lb. per hour of steam at 200 lb. per square inch for train heating and heating for the heavy fuel oil. To start the locomotive the Diesel engine is run to provide energy for motoring the turbine. At 5,800 turbine r.p.m. Diesel fuel is supplied to the burners, and the unit accelerates up to speed. After about 4½ minutes, and when temperatures are up to normal, the fuel system is automatically changed over to heavy oil and the oil-engine set is shut down.

FUEL COSTS OF DIESEL AND GAS TURBINE

In comparing fuel costs of the Union Pacific Diesel and gas-turbine fleets operating over the same stretch of track it is found that the final figures do not differ a great deal; the low price of the heavy fuel used by the gas turbines cancels the Diesel advantage of greater efficiency. There is nothing to choose between the two types of locomotives for ease of operation. Noise is by no means troublesome in the gas-turbine locomotive and soon recedes into the background when one becomes used to it. Normal conversation is possible in the cabin at all times. Despite the heavier axle-loading, the gas-turbine locomotive appears to be inferior to the Diesel on slippery rail, and the 12-axle heavier Diesel has advantages on heavy pulls at low speeds.

There are two prototypes in service in Great Britain, one of which was built by the Swiss firm of Brown Boveri and the other by Metropolitan-Vickers. The Swiss design is rated as 2,500 h.p. and burns residual oil. It has a single combustion chamber and heat exchanger. The maximum working gas temperature is 1,100 deg. F. The Metropolitan-Vickers' design is of 3,500 h.p. and uses gas oil. It has six combustion chambers but no heat exchanger. It is designed to work at a maximum temperature of 1,300 deg. F.

6·7 PER CENT. EFFICIENCY FOR GAS TURBINE

Various teething troubles usual with prototypes have occurred and have been largely overcome, but the rapid burning away of the combustion chamber in the Swiss design still appears to be causing a certain amount of anxiety. Both locomotives have given excellent haulage performances and appear to be almost identical in consumption and efficiency results. The oil consumption in actual service varies from 23·02 lb. to 28·3 lb. per mile equal to 2·47 gallons to 3·0 gallons per mile. These are equivalent to 1·93 lb. to 2·17 lb. per drawbar horse-power hour. On these figures the work-to-fuel efficiency is approximately 6·7 per cent., which is appreciably below the optimum full-load efficiency of 16·8 per cent. obtained on the test bench at Baden for the Swiss turbine unit. The explanation lies in the fact that a locomotive has an average load factor in normal service of only approximately 50 per cent. of the full-load capacity. The gas turbine with its compressor suffers from a steeply drooping characteristic of the efficiency curve at partial loading. It follows therefore that for successful operation the loading of a gas-turbine locomotive must be closely related to its designed output.

Earlier reference has been made to the various horse-power ratings of a locomotive. It is interesting to note that in the case of gas turbines, the power required to drive the compressor is approximately three times that of the power available for haulage; thus for a 2,000-h.p. locomotive the turbine unit or units must develop a total of 8,000 h.p. of which 6,000 h.p. is absorbed by the compressors. The thermal efficiency is limited by the maximum temperature which can be allowed for the gas passing through the turbine and with the present materials available is probably limited to about 1,300 deg. F. Metallurgists are making great efforts to develop suitable alloys which can be subjected to higher temperatures.

The temperature and atmospheric conditions of the ambient air and the altitude also exert an important influence on the performance. A fair figure for the thermal efficiency of a gas-turbine locomotive designed within the present limitations and operated in normal service conditions is around 18 per cent. on full load, and the efficiency falls rather rapidly for partial loading. Fig. 8 shows the characteristics for the Swiss prototype design, but steady improvement has taken place in more recent designs. The thermal efficiency is much below that of the Diesel locomotive and in common with all gas-turbine designs is expensive during idling and at partial loading. Few gas-turbine locomotives have been built to date and it is not possible to give a figure comparative with Diesel locomotives for first cost in quantity production, but it is improbable that this would be less than for Diesel locomotives, in any case, for many years. Any advantage which the gas turbine may offer appears to depend almost entirely upon the fact that it can use a cheaper oil and is very economical on lubrication and maintenance. No information is available at present of the life which may be expected or of the cost of maintenance.

The design of gas-turbine locomotives is at present in its infancy and experience to date is not sufficient to justify forming definite conclusions. The results given previously for the British prototypes are obtained in designs which were based on the knowledge available six years ago. Considerable progress has been made in turbine and compressor design since that date and still greater advances will take place in the future. It may be possible to counteract the drooping characteristic of the efficiency curve at partial loading by adopting dual-turbine power units which can be worked singly or in parallel, but there appear to be objections to this from the point of view of control and of first cost. There is little doubt that the design is definitely unsuited for shunting purposes and for locomotives which have to deal with general mixed-traffic conditions. It appears from results to date to be suited better to long-distance full-load schedules.

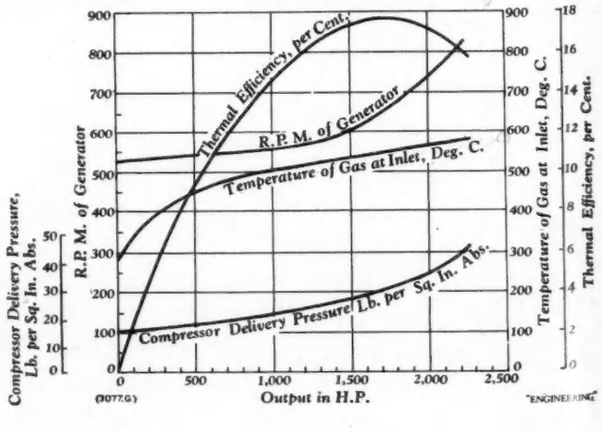


Fig. 8 Operating characteristics of the Swiss prototype gas-turbine plant for traction purposes.

COAL IN GAS TURBINES

The previous description of the gas turbine deals with designs which employ oil as the fuel, but Britain is primarily a coal country and the intensive studies now being made in the United States of the possibility of using coal are being watched with great interest. In 1945 the Locomotive Development Committee in the United States started on their research programme. They planned to produce a design for a 4,000-h.p. coal-burning gas-turbine locomotive which would burn less than 1 lb. of coal per rail horse-power hour. The problem is far from simple and has been divided into subheads. It is to design an apparatus which will: (*a*) deliver raw coal to a crusher or mill; (*b*) pulverise and dry the coal; (*c*) atomise the coal to the fineness necessary for rapid combustion; (*d*) deliver the atomised coal at an even and accurately controlled rate to the combustor under a pressure of some 150 lb. per square inch; and (*e*) finally get rid of the fly-ash from the products of combustion. This apparatus, together with storage for the raw coal to be carried, has to be provided within the weight and space limits of the locomotive. It must be remembered that for a given locomotive run the weight of coal to be carried and served is about twice the weight of oil required by an oil-burning unit and so the coal turbine starts out under a heavy handicap. The equipment needed for these functions is shown diagrammatically in Fig. 9.

The chief difficulty in the design of the gas turbine employing powdered-coal fuel now under development in the United States is to eliminate the fly ash or, alternatively, reduce it to such a small particle size that it causes no damage to the turbine blading. In the latest design of Dunlab separator,* the air stream conveying the fuel enters at the top of the outer tube and is giving a whirling motion by the radial fins, the larger particles are trapped in the lower part of the cylinder and blown out continuously by an air stream. The small particles return up the central tube. The complete separator unit consists of a number of tubes arranged in two banks. From test experience the conclusion is that blade erosion is prevented if the turbine is protected from the entrance of particles larger than 30 microns. On a test lasting 300 hours the ash fineness at the separator inlet was 37·4 per cent. of + 10 microns and 13·9 per cent. of + 20 microns. At the turbine inlet the size consist was 8·3 per cent. of + 10 microns and 0·6 per cent. of + 20 microns. In this test

* See ENGINEERING, vol. 177, page 563, 1954.

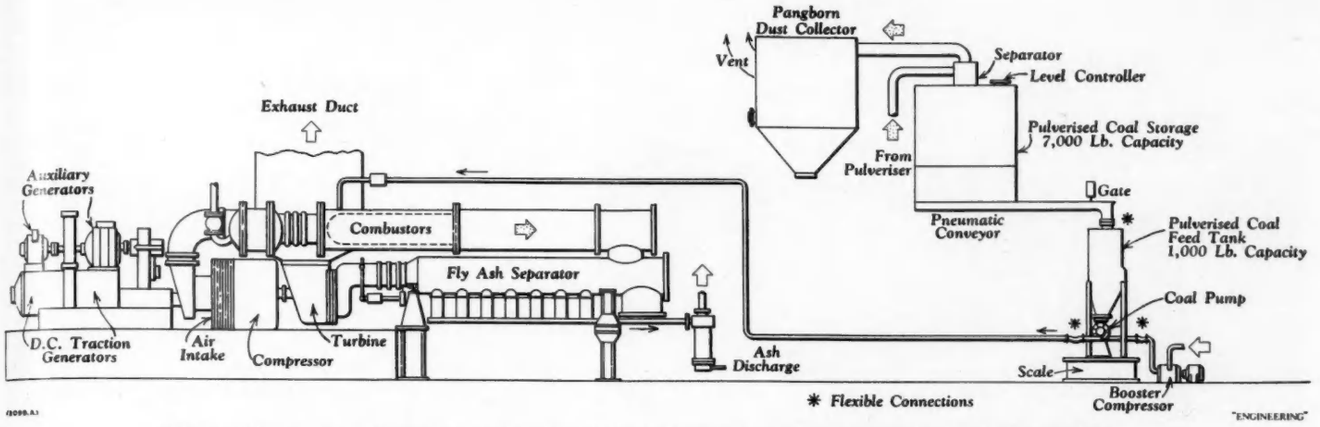


Fig. 9 Diagram of equipment of coal-burning gas-turbine locomotive under development in the United States.

the coal used contained 6 per cent. of ash and the average rate of burning was 2,410 lb. per hour. The average turbine inlet temperature was 1,060 deg. F. The power generated was 545,000 horse-power-hours and the average fuel rate 1·33 lb. per horse-power-hour. The average thermal efficiency was 14·2 per cent., which is low, due to the gas temperature being only 1,060 deg. F. A regenerator was not employed.

Development has now reached the stage when the complete power unit has been operated successfully on the test bench for 300 hours without damage to the blading. A complete locomotive has not yet been designed in detail and considerably more research and experimental work must be undertaken before the coal-burning gas-turbine locomotive can be placed successfully in service.

BRITISH GAS TURBINE

The difficulties with the elimination of fly ash and pulverisation of coal on the locomotive, which came to light during the American development, have led British designers to tackle the problem on an entirely different line. Britain being a coal producing country, it is obviously of advantage for British Railways to utilise indigenous fuel rather than import oil from abroad. On the other hand, every effort must be made to conserve coal resources by reducing the quantity required for railway services. With these two national requirements in view, a coal-burning gas turbine locomotive is being designed and built to the order of the Ministry of Fuel and Power by the North British Locomotive Company, of Glasgow, in conjunction with C. A. Parsons and Company, of Newcastle-upon-Tyne. The British Transport Commission are of course interested in this locomotive, which will be tested on British Railways.

The essential difference between this and previous designs is that it works on the exhaust heater or " dry boiler " principle. The exhaust heater resembles a fire-tube boiler, except that it heats air instead of water. Pulverised coal is burnt in the combustion chamber, the flame and heat passing through the tubes and out to exhaust. On the other side of the heat exchanger, i.e., in the space in the " dry boiler " surrounding the fire tubes, air from the compressor is heated to some 1,300 deg. F. The hot compressed air is then used to drive the compressor turbine and, in addition, the separate work turbine, which is geared through mechanical transmission to the locomotive wheels and provides the motive power. The great advantage of this system is that the compressor and turbines are fed with clean air and are not subject to wear or corrosion from ash or combustion products.

Two features of this cycle should be noted. Firstly, the compressor turbine can be run at the speed appropriate to the load, irrespective of the road speed of the locomotive. In combination with the heat of the burners the air fed to the work turbine can be controlled to give the requisite temperature and pressure, just as the fireman controls the head of steam in a steam boiler. There is a further similarity between " dry " and steam boilers in that to achieve the best economy in operation the fireman will have to allow for the " heat inertia " of the heat exchanger, which can provide a small reserve of power for short periods of overload. He will also have to anticipate stops and down-hill running to avoid waste of fuel in " blowing off."

GAS TURBINE'S GREATEST EFFORT AT STARTING

The second feature is that the separate work turbine, being independent of the compressor, can be directly coupled to the road wheels and thus run at a speed proportional to that of the locomotive. This is possible, due to the characteristic of the gas turbine giving its greatest effort when it is held stationary at starting, which is exactly one of the essential requirements of locomotive operation. This direct drive, therefore, saves the transmission loss inherent in electric or hydraulic transmission which is usually of the order of 15 to 20 per cent. The locomotive is of the double-bogie type, the drive being through cardan shafts and a reduction box which provides for reverse running and two alternative forward speed ranges. One of these is suitable for passenger work and the other for freight.

The residual heat in the hot air from the turbine exhaust is not wasted in this cycle, as this air is led to the combustion chamber where pulverised coal is blown in and burns with a fierce flame. A further economy is effected by using the final exhaust to raise steam in a boiler for heating passenger trains. It is frequently not realised what an amount of power is required for this purpose and it may surprise some to learn that a passenger locomotive pulling a heavy air-conditioned train may have to provide as much as 200 to 300 h.p. for the comfort of the passengers, in addition to its drawbar horse-power.

With modern techniques, pulverised coal is now available in this country in special tank wagons from which it can be conveniently blown through a pipe to any desired point. Advantage is taken of this in the new design to save the weight and complication of pulverising apparatus on the locomotive itself. The pulverised fuel is carried in a bunker on the locomotive, whence it is drawn through a controlled feed to the burners in the combustion chamber. It is, however, necessary to start the burner on oil and change over later to pulverised coal. Starting and warming up the heat exchanger takes about 25 min. A small auxiliary Diesel engine supplies the electric power during starting.

This development work is a typical British contribution to the advancement of the science of locomotive design. It is hoped that the new locomotive will be on trial next year. If successful, the new design will prove a formidable rival to the steam locomotive since it will burn the same fuel but use less than half the quantity required by the steam locomotive for the same work. Moreover, it shares with the Diesel locomotive the great advantage that no water is required for it.

THERMAL EFFICIENCY AS A YARDSTICK

It must be admitted that in this paper the emphasis has largely been upon thermal efficiency but it is advisable to offer a word of warning with regard to accepting this as a yardstick for comparison. Assuming that the designs and types of locomotive being considered are capable of operating and meeting the traffic requirements, then the final decision must be based entirely on the cost of operation per ton-mile, and although the cost of fuel is a very influential factor on the cost of operation, there are other considerations which are of equal importance. An increase in the thermal efficiency would normally reduce the cost of fuel, but unfortunately experience shows that the increased efficiency obtained by some types of locomotive is accompanied by an increase in first cost, and for many traffic conditions a better thermal efficiency can be purchased at too high a price in other respects. The main factors affecting the decision as to the best type and design to employ are : (*a*) the first cost of the locomotive and the standing charges involved; (*b*) the cost and consumption of fuel for the given operating conditions; (*c*) the availability for service of the locomotive; (*d*) the utilisation permitted by the traffic conditions; (*e*) cost of maintenance; and (*f*) reliability and freedom from withdrawal from service.

For the majority of traffic conditions, not only must Diesel and gas-turbine designs have an availability of more than 90 per cent. in order to offset their high first cost, but also the traffic utilisation conditions must be such that full advantage can be taken of this availability. It is doubtful if a locomotive working under normal operating conditions has an average load factor of more than 50 per cent., which may be a very serious consideration in design which becomes uneconomical at partial loading. If a coal-burning turbine design embodies the equipment to crush the coal then it must cost and weigh more than one using oil, and the justification for employing it would depend almost entirely upon the relative price of coal and oil and possibly upon the availability of each type of fuel. The matter is exceedingly complex but whatever may be the outcome of the research work now in progress, there is no doubt that considerable changes will take place in the near future.

In conclusion, the authors wish to express their thanks to the Institution of Mechanical Engineers, the Institution of Locomotive Engineers, the British Transport Commission, the American Society of Mechanical Engineers, and the Editor of the *Oil Engine and Gas Turbine* for information which has been made available and for permission to reproduce certain illustrations.

A report of the discussion on this paper is on page 368.

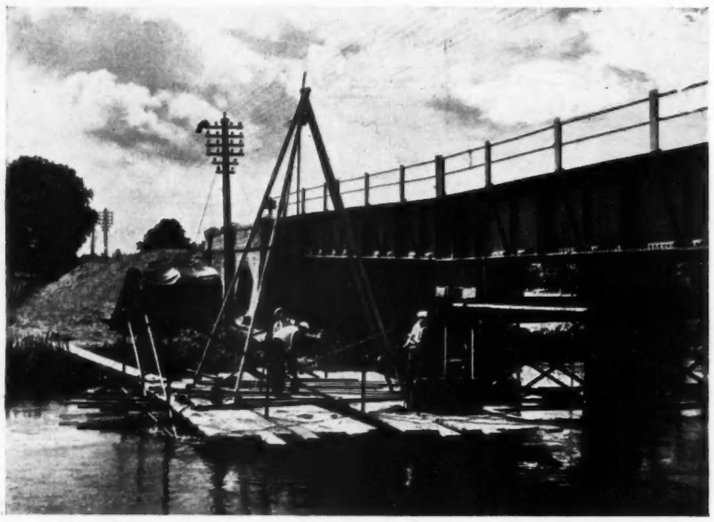


Fig. 1 Boring in the river at Romsey to ascertain the reason for the subsidence of the bridge.

Fig. 2 Hook Cutting in 1951, showing track upheaval caused by a slip in the adjacent embankment.

SOIL MECHANICS IN RAILWAY CIVIL ENGINEERING*

By A. H. Toms, B.SC., A.M.I.C.E.†

The era of railway building in the United Kingdom afforded what was probably one of the finest series of opportunities for geologists to profit from the operations of civil engineers. It was not, however, until about 1937-38 that the scientific study of the physical and engineering properties of soils was taken up by one or two selected civil engineers in English railway employment with a view to a better understanding of the many landslips and other soil problems with which British Railways are faced. The author was fortunate to be one of the selected engineers. The early development of soil mechanics as a science owes most to pioneering work in other countries, notably that of Dr. Karl von Terzaghi, now in America. However, a small team of able scientists was formed at the Building Research Station, Watford, in the 1930's and their work quickly stimulated the civil engineering fraternity in this country. This work soon proved that something more than the purely geological data hitherto available concerning soft strata might be obtained by appropriate tests of strength and other physical properties.

Soil mechanics, which is the study and application of the physical properties of soil to civil engineering problems, can be considered as the common meeting ground of the orthodox geologist and the civil engineer. The association of geologist and civil engineer is nevertheless as vital to-day as it ever was and is exemplified on British Railways by the fact that no project of any consequence is ever put in hand without reference being made to the Geological Survey and Museum for any data which they may possess. Yet the information which the geologist, in the generally accepted sense of the term, has been able to offer on purely geological grounds has often been inadequate to enable the engineer to determine such questions as, for instance, the stable slope of a cutting or embankment composed of clay, or the ideal shape or thickness of a tunnel lining.

Likewise, there are many other problems in which the civil engineer needs to know the physical properties of the soil, since these determine its ability to support the loads from structures such as bridges and buildings and also the long-term settlements that occur under loads which may be imposed without risk of sudden failure of the ground under and round the foundation. Though much has yet to be learned about the physical properties of soil, a stage has already been reached when very satisfactory correlations can be effected between the safe bearing capacity or probable settlements estimated from laboratory tests on the soil and the actual proved values on the job. From laboratory studies of the swelling characteristics of clays new light is being thrown on old and thorny problems such as the pressures for which retaining walls and tunnel linings should be designed.

The following notes are but a very brief sketch of the application of the new science of soil mechanics to the solution of civil engineering problems on the Southern Region of British Railways. Nowadays, no major civil engineering project or problem is handled by the Chief Civil Engineer's Department without the earthwork or foundation aspect being referred to the Research (Soil Mechanics) Section for advice.

If the geological and other data are still insufficient, a small team with a boring rig and special soil-sampling equipment is sent to the site and holes are bored or trial holes excavated in the ground so that samples may be obtained for testing, either on the spot with portable machines or in the laboratory. Fig. 1 shows a test boring in progress at Romsey to ascertain the causes of the settlement of the bridge. A small but well-equipped soils laboratory has been set up in which a variety of tests can be performed on the "undisturbed" and disturbed samples of soil, to determine such properties as soil type (mechanical grading analysis, etc.), moisture content, liquid limit and plastic limit (in the case of cohesive soils), compressive and shear strengths under various states of stress or pore-water drainage and pressure, permeability to water, and consolidation under applied pressure. In the event of the site investigation necessitating the use of special equipment, or boring to depths exceeding those for which the necessary plant is held by the Chief Civil Engineer's Department, contracts are placed with specialist firms for the work of boring and soil sampling, and sometimes for testing also.

LANDSLIPS

Every traveller on British Railways will have noticed that frequently during the winter slips of embankments and cuttings cause a considerable amount of trouble. Fig. 2 shows a typical slip in a cutting at Hook, which upheaved the adjoining track. Most of these difficulties arise because, when the railways were first constructed, there was relatively little experience, apart from work on canals, to enable the engineers to judge the slopes at which such earthworks in clayey or silty soils might remain stable. Though there has been a great deal of trouble with many such earthworks a tribute is nevertheless due to the early pioneers on account of the fact that so much of their work has behaved well for over a century.

Where banks or cutting slopes give trouble, and time permits, exploration by boreholes can often enable the depth of the surface on which sliding is occurring to be determined, both from the study of the soil strength profile down the boreholes and by ascertaining the depth at which any borehole is sheared off by continuation of the slip movement. When armed with this information, together with the knowledge of the location of any water sources in the cutting or water pockets which may have formed in the embankment, the civil engineer with soil mechanics training is in a position to determine the most effective and economical remedial action.

In the case of a cutting through open country, where there may be discharge of ground and surface water into the top of the cutting slope, and the land value is relatively low, the most economical treatment for the slip may be to trim the unstable part to a flatter average slope, possibly with a "berm" (or more level portion) half way up, and to intercept as much as possible of the water by a deep trench with pipe or channel drain along the top of the cutting. This trench would be backfilled with an adequately pervious medium such as ballast or rock-crusher dust, in which the voids are sufficient but not so large that the clay will flow in readily and clog the drain. A full discussion on drains has no place in this short review. Suffice to say that it is far from being a simple problem.

If there is much water in depth in the cutting slope, and particularly if land cannot be acquired for trimming back the top, it may be necessary to construct deep "counterfort" drains into it at say 30 to 40-ft. centres to tap the water and dry out the slope. These drains take the form of trenches excavated through the slip surface, and with a pipe or channel drain laid in the bottom

* Paper read at a Joint Meeting of Sections C (Geology) and G (Engineering) of the British Association at Bristol on Monday, September 5, 1955.

† Research Assistant to the Chief Civil Engineer, Southern Region, British Railways.

on concrete or grouted bricks and with a coarse granular fill compacted in between finer graded fill (or handpacked brickbats) up the trench sides. If these measures are insufficent to hold the slope then a retaining wall or row of sheet piling may have to be constructed to hold the slip from encroaching on the railway. Calculations taking into account the mechanics of the slipping masses, the water pressures, and the resistances offered by the soil, often enable a far more rational approach to be made to the remedial measures than was possible before the advent of the science of soil mechanics. Fig. 3 indicates a deep slip in stiff fissured Weald clay which occurred at Sevenoaks cutting in 1939. The nature of the slip and the remedial measures are shown. In this figure the moment tending to cause slip is W L and this is opposed by the shear strength C of the clay round the slip surface acting at radius R. The black dots indicate the positions from which samples of clay were taken after the slip and tested for shear strength.

The treatment of embankment problems is similar in principle to that of cuttings. Once the weak zones and internal water accumulations have been revealed by borings and soil tests, calculations soon indicate the scale of remedial measures required to give approximately any desired factor of safety against further movement. Where land at the toe of such a bank slip is cheap it often pays to buy a strip and tip a "berm" of suitable filling against and on the toe to offer increased resistance to forward thrust. Alternatively sheet piling must be driven or a retaining wall must be built if the land cannot be acquired economically. In many cases embankment slips are drained in the same way as cuttings, but frequently other remedial works such as "toe berming" are also necessary to achieve the desired stability. Incidentally, a cheap and sometimes very effective way to drain water pockets which have formed in pervious fill on the tops of clay embankments is to jack steel tubes in from a point near the bottom. The front lengths of tube are perforated to admit the water and the leading one has a pointed spear head of somewhat larger diameter to form a hole of larger size than the pipes.

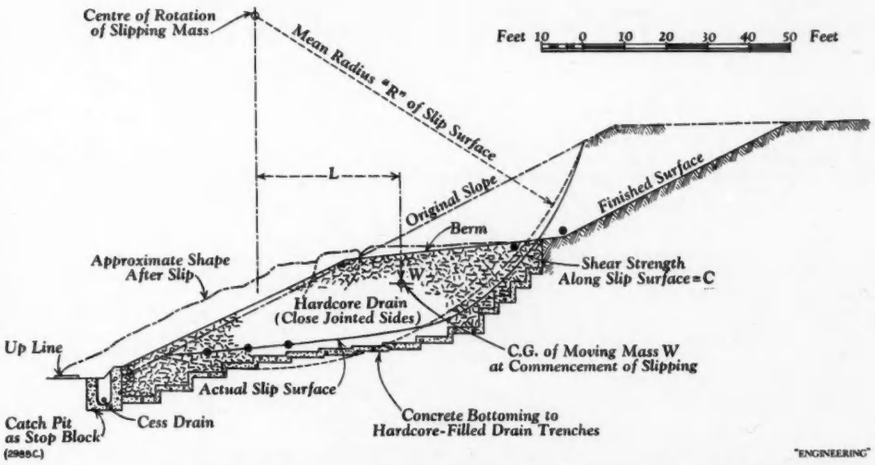


Fig. 3 Cross-section of a slip in a cutting through stiff fissured clay showing the actual slip surface, the expected slip circle (determined from the characteristics of the bank) and the remedial measures adopted.

COASTAL LANDSLIDES

The biggest single landslip problem affecting British Railways is that of the coastal landslips at Folkestone Warren illustrated by Fig. 4, the photograph having been taken just after the great 1915 movement had disrupted the railway for about 1½ miles. There the railway runs for two miles continuously across a vast expanse of slipped chalk and Gault, resulting from shear failure of the Gault in its basement bed on top of the Lower Greensand. The middle and lower chalk form cliffs rising to + 550 O.D. behind the wide stretch of slipped ground, while the Gault underlies the whole of the affected area. In 1938, the author was directed to commence a research into the nature of the slips which were once again beginning to threaten the stability of the railway. This research and its continuation ten years later by the author's one-time assistant, Mr. A. M. M. Wood, have been described in detail elsewhere.* Briefly, test boreholes were sunk over a wide area down to depths of up to 300 ft., and many soil samples were extracted for visual inspection and special testing. The information so obtained on soil type, fossil content, strength and moisture content enabled the hitherto unknown mechanism of slipping to be unravelled. In this work fossil identification and zoning proved of the utmost value. It was found that, in this particular case, more accurate determinations of the amounts of disturbances of ground blocks were possible by study of the fossils than from soil mechanics tests alone. Fig. 5, page 386, is a cross-section of the Warren showing some of the boreholes and the slip zones located by them. In the past geologists had propounded many theories to explain these Warren slips but, to the author's knowledge, only one proved to be the correct explanation, which is that of deep shear failure extending down into the Gault basement.

As a result of the research at the Warren an extensive programme of stabilisation works has been put in hand as follow. (i) New sea walls farther out to sea, with filling behind protected by concrete slabs. The object of this work is to provide toe weight on the foreshore which is upheaved by slips, and also to arrest erosion in those vulnerable areas. (ii) Drainage of water out of the slip by means of a new tunnel heading. (iii) Overhaul of all existing drainage headings and groynes. (iv) Repair of old groynes and provision of new ones.

* A. H. Toms. "Folkestone Warren Landslips: Research Carried out in 1939 by the Southern Railway Company," Railway Paper No. 19, Inst. C.E., 1946. A. M. M. Wood, "Folkestone Warren Landslips Investigations, 1948-50"; N. E. V. Viner-Brady, "Folkestone Warren Landslips: Remedial Measures, 1948-54," Railway Papers Nos. 56 and 57, Inst. C.E., 1955.

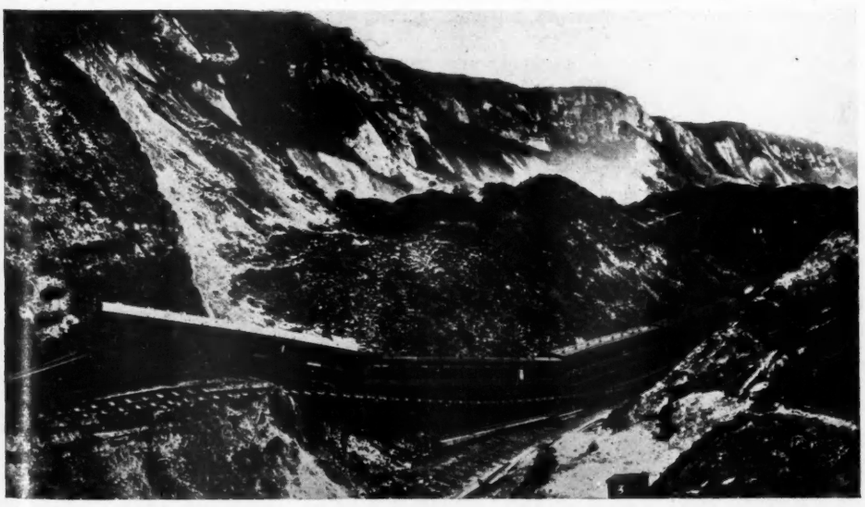


Fig. 4 Folkestone Warren slip in 1915. The movement disrupted the track for 1½ miles.

FOUNDATIONS OF STRUCTURES

When any new structure, such as a bridge, signal box or electrical substation, is built it is essential to ensure, so far as possible, that the foundations shall distribute the load into the ground in such a way that there shall be no immediate failure of the ground in shear and also that any subsequent slow settlements shall be sufficiently small or of such a character that they do not upset the building or the functioning of its equipment. To this end borings are sunk at each site to a depth of not less than 1½ times the width of the proposed foundations and 4-in. diameter soil cores are obtained from various depths. From these samples the shear strength and consolidation characterisitcs of the various strata are obtained and thus it is possible to calculate the required form and depth of the foundations. In the case of a clay soil the ultimate bearing capacity of a footing near the surface is known to be about six times the soil shear strength, but the working stress is kept well below this value to provide a factor of safety and also eliminate risk of slow creep deformation resulting in settlement.

It has been found by experience that in many cases of substations, signal-boxes and bridges the design of the foundations is determined, not by the shear strength of the ground but by its consolidation settlement under the load. Though the shear strength of the surface soil may be adequate to sustain the bearing pressure of relatively small footings, a raft over the whole floor area or a piled foundation has frequently to be adopted to reduce the settlements to acceptable amounts.

One of the most difficult problems which arises in connection with the estimation of the probable settlement of structures is that of a group of piles which may be required to transmit the foundation load into a layer of soft compressible soil, the thickness of which is too great to permit the piles to penetrate to firmer material below. It is evident that the load distribution by a pile to the ground around it must vary as consolidation of the ground takes place under the stresses imposed by the pile. Nevertheless, it has proved possible to arrive at reasoned

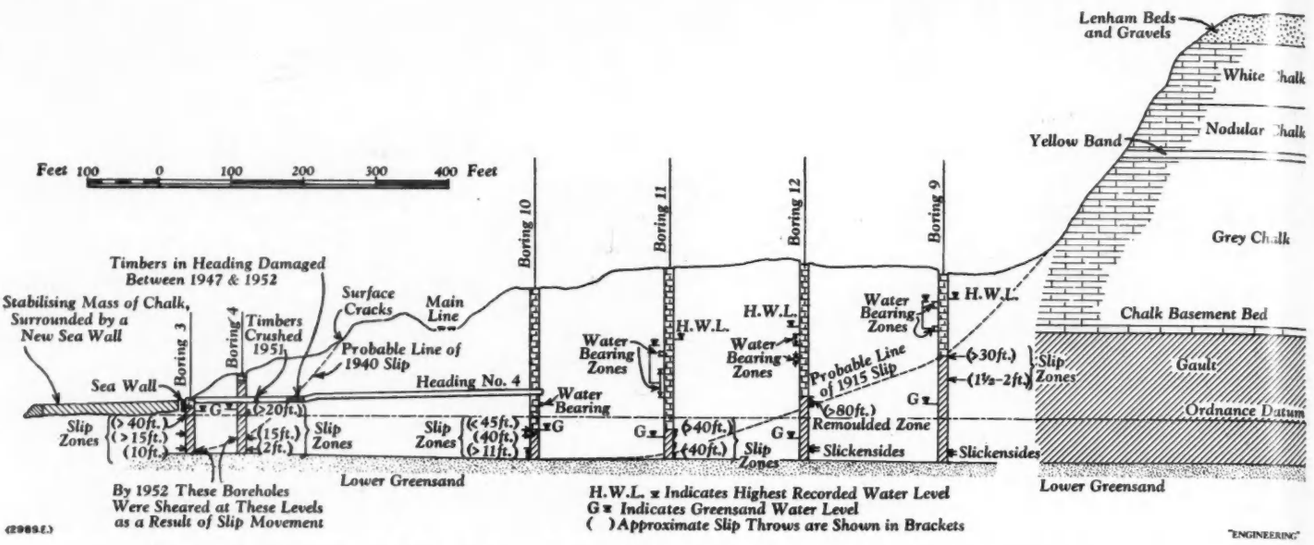


Fig. 5 Folkestone Warren. Typical cross-section showing boreholes and heading put down to locate the slip zones.

estimates of probable settlements in such cases, a typical one being that of proposed pile groups for new side spans to the Kingsferry Bridge over the Swale where there is a great depth of soft alluvium overlying London clay of varying strength.

TRACK FORMATION PROBLEMS

Owing to the passage of time and the increase of axle loadings over tracks with inadequate depths of ballast and roadbed material, much trouble has been experienced with clay pumping up as mud around sleepers and heaving up in ridges of solid clay at the sides of the tracks and sometimes between sleepers. Fig. 6 shows a typical large clay heave between tracks, while Fig. 7 indicates the type of water pocketing under the tracks which results from these soil failures. The black dots indicate points from which clay samples were taken. In 1940, the author made the first scientific approach to this problem by taking "undisturbed" samples of the soil from below the tracks and relating their bearing capacity to the approximately calculated stresses imposed by trains. The result, surprising to many at first, was that, apparently, the soft clay ground was overstressed to a depth of over three feet by the passage of heavy axles. This appeared to explain the progressive slow plastic failure of such track formations.

The war intervened in these researches but methods were developed subsequently for determining the required depth of new track formation to replace old unstable roadbeds.* Since the war, much of this work, described as "track blanketing," has been carried out using mainly a rock-crusher waste dust as the new formation material. This has high internal friction and good load-spreading powers while being sufficiently fine grained to hold down clay which might otherwise tend to become soft and pass up through the voids due to the pulsating action of the live loads on the track. Much fundamental work still remains to be done on this problem but the practical applications so far have been encouraging.

It goes without saying that where such track troubles occur in cuttings, or even on wide flat expanses, line-side drainage systems, designed to suit circumstances, are highly desirable. The essential is that the backfill material over the drain pipes shall be fine enough to hold back the clay while still permitting the passage of water.

TUNNEL PROBLEMS

Typical of the application of soil mechanics to the solution of tunnel stability problems is the case of Bo-Peep Tunnel, Hastings. This double-line tunnel, passing through the Wadhurst clay, is of brick-arch construction and, originally, part only of the length had a brick invert under the tracks. A few years ago it was noticed that the tracks near the western end of the tunnel were rising, the side walls were closing in and houses and a road over the top had started to subside. Steps were taken at once to put temporary supports in the tunnel to arrest the movement. Simultaneously, an intensive research was begun into constructional and geological records, and a programme of soil mechanics investigation was put in hand to ascertain the nature and strength of the soil behind the side walls and under the footings and tracks in order to establish the nature and causes of the movements. Very careful measurements were also taken inside the tunnel at frequent intervals of time. These investigations soon revealed that the movements were due to shear failure of the ground under the side-wall footings, there being no invert to this part of the tunnel floor. This had been brought about by very slow but progressive softening of the ground under the tracks on account of the combined action of percolating water and the dynamic effects of rail traffic.

It was immediately apparent that both vertical and lateral support to the tunnel walls was necessary and therefore a strong reinforced-concrete invert was built throughout the affected length of tunnel. As it had become impracticable to repair the weakened brickwork, cast-iron underground tube railway-station segments were used to enable the tunnel to be enlarged and strengthened. As much of the remainder of the tunnel was found, by boring and probing, to be without invert, the question arose as to whether such attempted collapse might occur elsewhere. Fortunately, research brought to light an almost complete picture of the geology which showed that there was almost certainly a fault zone in the region of the failure which had been an ever-present weakness in the ground. It was therefore concluded that there was no evidence to suggest the development of further trouble elsewhere in the tunnel.

Following this incident, extensive soil-mechanics investigations were made in both Hastings and Ore tunnels and major strengthening works, involving the invert, were put in hand. It may be mentioned here that very recent research into the pressures developed by London clay on tunnels has been applied to the design of new tunnels for the track duplication to start soon on the Eastern Region in the Hadley Wood to Potters Bar section. The repeated collapses during construction of some of the railway tunnels through London clay is an illustration of the extreme importance of the knowledge now being acquired as a result of the application of soil mechanics.

RETAINING WALLS

Though for many years there have existed reasonably sound theoretical methods of determining the pressures likely to be exerted by

Fig. 6 Heaving of a weak-clay formation between tracks occurs due to the continual pumping action of passing trains. The remedy requires deeper roadbeds to be laid down.

* A. H. Toms and W. F. Beatty. "Remedial Measures for the Improvement of Railway Track Formations." Railway Paper No. 37, Inst. C.E., 1950.

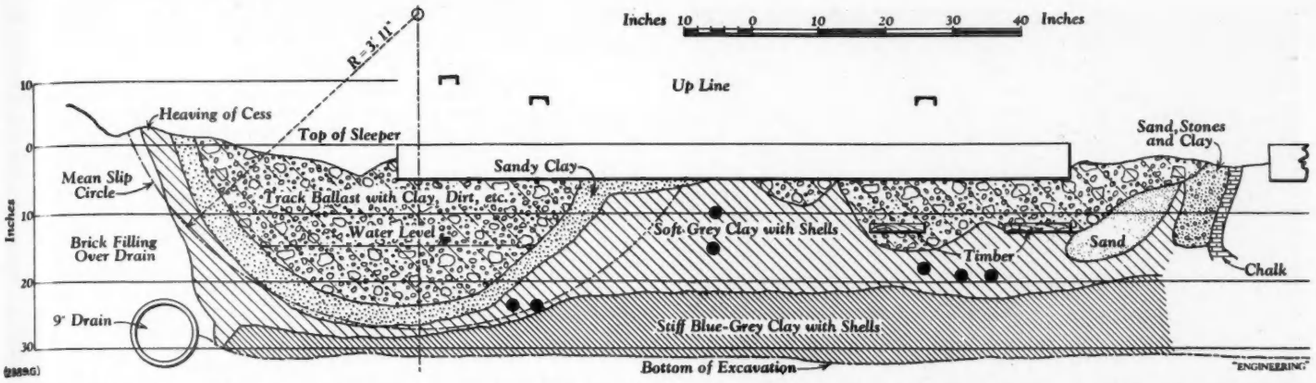


Fig. 7 Typical cross section through weak track on a clay formation, showing the development of waterlogged ballast pocket below the end of the sleeper and heaves of clay in the cess and the 6-ft.

granular non-cohesive soils on walls and other structures, the pressures likely to be exerted by clays remained, until fairly recently, the subject of much speculation. Even though there is still a wide field for research in this matter the application of soil-mechanics testing has enabled some at least of the unknowns to be clarified. It is now possible to make far more intelligent estimates of the order of the forces likely to be exerted on earth-retaining structures, particularly in the case of softer clay strata. These soils do not involve the difficulties presented by lack of homogeneity which is found in the stiff fissured over-consolidated clays such as the Gault, Weald and London clays. The latter clays and others like them were subjected, during their geological history, to overburden pressures often far in excess of those under which they now exist at the levels where they are exposed by engineering works. Consequently, they are frequently found to be in a metastable state in which they are eager to absorb water and, in so doing, these clays can often exert large swelling pressures. These pressures may bear a very different relation to the depth of ground retained by the structure, from that in the case of granular soil such as sand.

Moreover, if swelling is not resisted and absorption of water by the clay is unchecked it will gradually soften down and lose strength. This applies whether the clay is fissured or not, but in the case of fissured clays irregular absorption of water along the fissures tends to break up the clay. Its bulk strength may then be very difficult to estimate from tests on small specimens. It is this aspect of the problem which causes most difficulty at present in the estimation of pressures on earth-retaining structures and also the long term stability of cuttings through these clays.

A typical application of soil mechanics technique to the problems of retaining-wall stability is that of Medina Wharf, Cowes, Isle of Wight. Here a very large mass-concrete wharf wall, founded along the river side, in clays of the Osborne series, has undergone slow displacements due to the pressures resulting from the weight of coal and shingle tipped into large bins on the wharf. The strength of the soil in front of and behind the wall and at other points has been determined from laboratory tests on samples extracted from borings. From these data and the known movements over a period of years it has been possible to estimate at what depth and in what manner the soil under the wharf and river bed has been failing. This, in turn, has enabled a logical remedial scheme to be designed, whereas, without the soil-mechanics analysis, such a design would be largely intelligent guesswork. In this job samples of clay kept under sustained loading were found to deform plastically at stresses well below those required to cause rapid shear failure. This was a vital link in the analysis of the wall movements.

The cutting in which the railway runs through Woolwich Dockyard Station is bounded in part by high brick retaining walls, now roughly 100 years old. Slow creep movements had occurred of one wall which was due for demolition to make way for station improvements. Opportunity was taken to make strength tests of the clayey sand soil behind and under the wall and to correlate these with a stability calculation of the wall itself. The wall was found to be far too thin and narrow at its foundations to have remained stable had there not been enough clay in the sand to give it slight cohesion. The very slow forward movement of the wall was probably due to the slight swelling of the clay

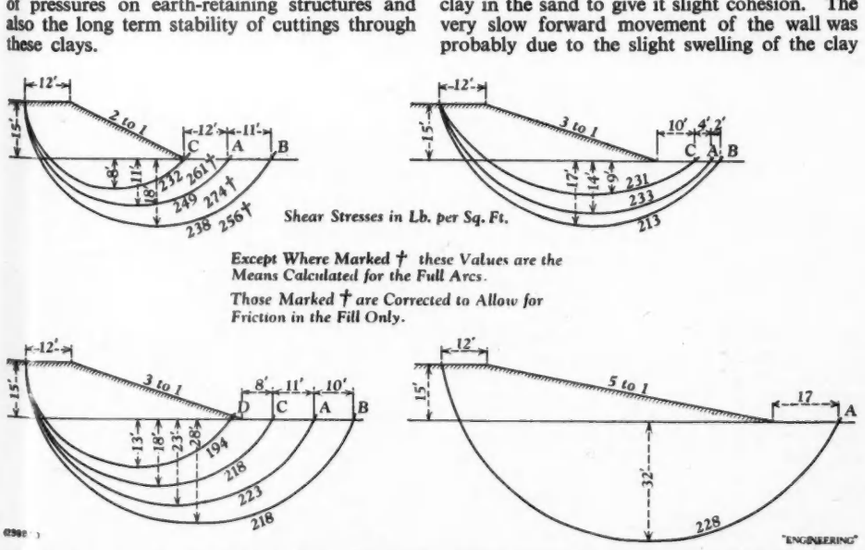


Fig. 8 Temporary sea wall at Birchington. The diagrams show the calculated shear stresses in the soil under banks with different side slopes.

content of the soil on account of seasonal changes of moisture content. This research emphasised the marked effect, on soil pressures, of a small clay content in sandy strata which remain reasonably well drained.

Excavations Alongside the Railway.—A large number of instances arise where development of land alongside the railway for brickworks, sand and gravel pits, etc., involves the imposition of restrictions on the workings on the side nearest to the line on account of the risks of affecting the stability of the railway. The legal aspect of these problems is outside the scope of this paper. Mention should be made, however, that the limiting profile to which excavation can safely be taken is now settled on the basis of a knowledge of the soil type and its probable long-term behaviour, determined both by previous case histories and by soil mechanics considerations. Apart from the presence of ground water in many of these excavations, the problem is analogous to that of the determination of the safe slopes for railway cuttings in corresponding strata.

Underground Mine Workings.—The effects on the railway of surface settlement due to underground mine workings are not of very great consequence on the Southern Region. On other Regions, however, the British Transport Commission's mining experts are very much involved as are, of course, the Regional Chief Civil Engineers, in keeping pace with the effects on structures and track, and also in providing, in the design of new structures, for flexibility to allow for settlements.

SEA-DEFENCE EMBANKMENTS

British Railways suffered extensive damage during the floods which occurred in January, 1953, as a result of the unprecedented combination of tide and gale surge in the North Sea. Destruction of the sea walls at Birchington, Kent, permitted the sea to overtop the railway embankment some half mile inland, with the consequent destruction of a great length of the railway track and formation. It was decided that British Railways should join forces with the Kent Rivers Board in the construction of a new sea-defence embankment close to the seaward side of the railway bank. Very large quantities of chalk were brought to the site to form a wide embankment intended to be 15 ft. high. Test borings, put down into the marsh revealed a considerable depth of soft alluvial soil, some so weak as to be almost fluid. The author's staff therefore quickly made calculations of the probable stability of this soil under the proposed new bank, then partly constructed, and it was found that the marsh deposits would be unlikely to stand safely the shear stresses imposed by a bank of the full height proposed. Fig. 8 shows some of the calculations made which indicated that flattening of the side slopes of the embankment would not be effective and that the bank height was the critical factor. Within an hour of this discovery a message was received in the author's office that the bank had,

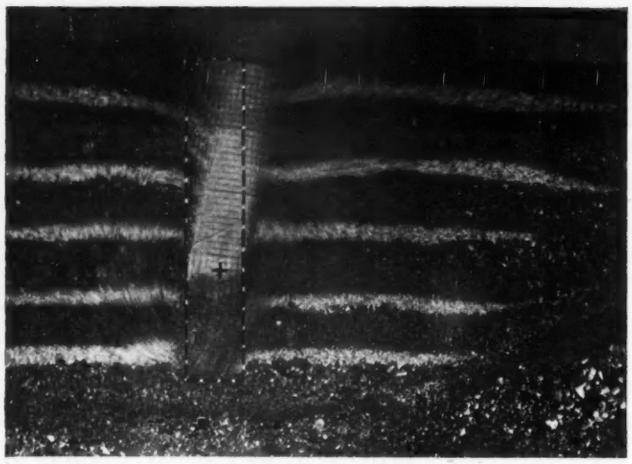


Fig. 9 Model study of soil displacements occurring during overturning of the foundation for an overhead electrification mast taking a horizontal pull to the right at the top.

in fact, begun to fail by subsiding and splitting along the centre, due to heaving up of the marsh soil along both sides of it. This was unfortunate but, at the same time, a fine example of the information which can be given by soil mechanics tests and analysis. Had it been possible to produce the analytical result sooner some warning would have been given to the bank builders that they might have to restrict the height as, in fact, had to be done finally.

In addition to the foregoing, stability analysis calculations were made, on the basis of further soil tests, to determine the probable long-term settlements of the embankment due to compressure of the underlying soil and expulsion of water from it. These ranged from about 6 in. to 29 in.

GEOPHYSICAL SURVEYS AND CLAY SAMPLING

In so far as they depend on measurements of the physical properties of soils, geophysical methods of subsurface exploration fall within the civil engineers' term "soil mechanics," and these methods are being used increasingly for civil engineering soil surveys. The only application so far of these methods by British Railways S.R., for such a purpose was a recent experiment to see whether the variations of ground electrical resistivity over the top of a tunnel would enable an old hidden construction shaft to be located. It is satisfactory to be able to record that a resistivity peak was measured at the point where old deed plans indicated that the shaft might be.

The other lecturers* will have dealt to some extent with some of the problems encountered in obtaining "undisturbed" samples of clay and arriving, by various tests, at a reasonable estimate of the actual strength of the soil as it exists in the ground. In practice, it is impossible to withdraw a sample from the ground without some disturbance either of the particle arrangement of the periphery (at least), moisture content, or state of internal stress. Particularly in the case of stiff over-consolidated clays, such as the unremoulded Gault at Folkestone Warren, it is extremely doubtful whether the structure may not have been disturbed to a considerable degree by the driving in of even the thinnest and sharpest sampler tubes which will stand up to the driving effort. In an attempt to overcome this difficulty, a special rotary sampler was developed experimentally by the author several years ago. This had an outer rotating sleeve bearing externally both cutting teeth and a helix to remove the soil "shavings," while inside was a "floating" sleeve on ball bearings to receive the core as the sampler passed down round it. This tool seemed to justify further development.

* P. L. Capper, "An Elementary Introduction to Soil Mechanics," published on page 348 of last week's issue, and F. D. C. Henry, "Soil Mechanics Aspect of the Design of Foundations," to be published subsequently.

The vane-tester has proved of considerable use in making *in situ* strength tests of unconsolidated alluvial deposits such as are found in the marsh at Birchington, Kent, and the river valley at Newhaven Harbour, Sussex. In the former case, the silty-clay deposits were so soft in places that it was extremely doubtful how much disturbance was caused by forcing in the sampler tube; there was also great difficulty in withdrawing a sample with the standard sampler. By coupling two sampler tubes together end to end better sample recovery was achieved. The vane tester largely eliminated both these difficulties.

At Newhaven, there was less difficulty in sample recovery but the soft silty-clay soil proved to be rather sensitive to disturbance and it lost about three-quarters of its strength on remoulding without change of moisture content. It was found that normal triaxial and other compression tests on samples gave much lower strength values than the vane tests, indicating the marked ill effects of normal sampling techniques on such sensitive soils. Some Norwegian clays are so sensitive that they become virtually fluid when disturbed. This has been the cause of a number of landslides.

Compaction of Soil.—A very important branch of soil mechanics is that concerned with the behaviour of re-deposited soil under loading. In so far as railway tracks are laid on varying depths of fill it has been essential to make a study and tests of the effectiveness of various types of mechanical plant for compacting such fill. It will be appreciated that, since locomotive loading on a track is very heavy, any fill to be laid under a track should be compacted to such a density that little or no subsequent compaction by the trains will occur. In this connection tests are made of soil grading, moisture content and density so that the optimum conditions for any required result can be determined.

MODEL EXPERIMENTS

The solution of many practical soil mechanics problems by full-scale tests in the field would be extremely costly. However, if the soil characteristics at a given site are such that they can be simulated satisfactorily in the laboratory, it is often possible to devise experiments with models whereby the behaviour of the full-scale structure can be predicted with reasonable accuracy. A typical instance was a series of model tests carried out recently in the author's laboratory to determine the mechanism of soil failure around the foundations of the tall electrification masts required to sustain a horizontal force at the top. The model masts with various sizes and shapes of foundations were tested in a large bin of uniform soil having a glass side so that the soil and foundation movements could be observed. The general mechanism of the movements was determined by recording, in each test, several successive stages of movement all on one photographic negative. Fig. 9 shows typical soil displacements during one such test. The original position is indicated by dotted lines and the overturning movement was to the right at the top. A cross indicates the centre of rotation, and the movement of the soil particles is shown by the blurring. Lateral loading tests were then made, with the foundations well away from the glass, in order to determine the most economic proportions for the foundations. Full-scale tests elsewhere confirmed completely the predictions made from these model tests. Similar model experiments have been completed recently to determine the length of steel sheet piles required to resist the forward thrust of the Medina Wharf retaining wall referred to earlier. Another problem, solved more easily with the aid of model tests, was the permissible loading, by a block of flats, of the ground close to the top of a railway cutting through sand.

EFFECTS OF VEGETATION ON THE STABILITY OF EARTHWORKS

Vegetation of one sort or another is Nature's provision for protecting the bare soil, to a certain extent, from the destructive effects of changes of weather. Of recent years a more scientific study has been made of the seasonal fluctuations of moisture content below the soil surface which, particularly in the case of clays, has been responsible, in many places, for destructive differential settlements of buildings and bridges on account of the variable shrinkage and swelling effects produced in the soil. There seems no doubt that the practice of clothing embankment and cutting slopes with grass is justifiable in the interests of arresting surface cracking and erosion, but opinions are far from unanimous as to the value or otherwise of trees on slopes. Though the foliage may minimise the surface effects of the sun, and the roots may have a bonding and drying action to a variable depth, the fact remains that many clay embankment and cutting slopes have failed by shearing at such depths that the trees have gone bodily with the soil, the parts of the root systems which penetrated the slip surface having been too fragile to help appreciably in holding the slope. There is, however, no doubt whatsoever that some trees with extensive lateral root systems can cause serious damage to buildings founded on clayey soil near them due to the excessive changes in moisture content produced by the root suction when growing. This matter was debated at length at the Conference on Biology and Civil Engineering held at the Institution of Civil Engineers in 1948.

CONCLUSION

In conclusion two further examples may be quoted of the continuing relation of the civil engineer and the geologist. Not long ago an investigation was made jointly by the Geological Survey and the author of an extensive landslip area which was giving rise to disquiet. Before the author could advise on the engineering implications it was necessary to make a geological survey from which the probable mechanism of the movements was deduced by analogy with a somewhat similar slip area which the author had investigated earlier by soil mechanics methods. The second example is that of a test boring sunk to determine foundations for a new bridge. After passing through about 35 ft. of silt, a very hard shelly stratum was struck which made hand boring very tedious. The geological map had given the impression that London clay of unknown strength might be encountered below the alluvium. The Geological Survey soon confirmed that the boring must have just missed the edge of the London clay and penetrated into Woolwich beds. Since these are known to provide adequate bearing capacity further boring was unnecessary.

The author hopes that he has succeeded in showing that orthodox geology and soil mechanics are both essential to the proper assessment of civil engineering earthwork and foundation problems, and that soil mechanics can, most logically, be considered as the common meeting ground of the geologist and the civil engineer.

SERVICE LIFE OF HELICOPTER BLADES

RUGGED DESIGN AND REALISTIC TESTS

Preceding the annual dinner of the Helicopter Association of Great Britain, which took place on Thursday, September 8, at the Dorchester Hotel, London, a lecture on the "Design, Development, Production and Servicing of Helicopter Rotor Blades" was given by Mr. R. Allen Price and Mr. Frank L. Stulen, of the Parsons Corporation, Michigan, U.S.A. After reviewing briefly the design of helicopter blades and the increasing use of metal-bonded constructions, the lecturers described methods and results of blade fatigue testing in their own company. They then discussed manufacturing costs and, finally, considered the behaviour of blades in service and the necessity for a rugged construction. We give below extracts from those parts of the written paper dealing with fatigue testing and with the blade in service.

MODIFIED PROT FATIGUE TEST

In determining the safe life of helicopter rotor blades, the endurance limit for completely reversed stress in flapwise bending is considered to be the most important structural characteristic. A modified test of the type developed by Marcel Prot has two main advantages. There are no run-outs resulting in specimens with unknown endurance limits, and testing time is considerably shortened. The method mainly involves running the specimen at some alternative-stress level below the endurance limit for a chosen number of cycles. The stress is then increased by a small increment and the testing is continued for the same number of cycles. The procedure is repeated using the same stress and cycle increment until failure occurs. The ratio of the stress increment to the number of cycles per step is termed the loading rate. A typical loading rate would be 2,000 lb. per square inch increase for each step of 200,000 cycles of stress.

The procedure is repeated to provide many failures at three different loading rates. The data are plotted to show failure stress versus the square-root of loading rate. For steel, this plot is a straight line and where it crosses zero loading rate (or zero increase in stress per step), the endurance limit is indicated. Using one vibrator, 45 specimens were tested at 100 cycles per second in a period of eight weeks. This resulted in 45 separate values for the endurance limit. The classic S-N type of test for the same number of specimens would have taken at least 40 weeks. Comparisons of the results obtained by other methods have shown that the Prot-type test results in a satisfactory approximation of the endurance-limit scatter indicated by the S-N test. Which method, if either, provides the real endurance limit is open to question. The Prot-type test lends itself to the study of endurance limit in terms of stress-scatter while the S-N curve seems to provide a better basis for studying life-scatter at any particular stress level. Since long life is desirable, the endurance limit stress-scatter was analysed, and the Prot-type test was chosen as being more applicable.

TEST SPARS CHOSEN AT RANDOM

Blade spars were chosen at random for test specimens, in the as-fabricated condition, complete with surface scratches due to rolling, decarburising, etc., and nicks and scratches received in handling or corrosion. The test values are thus applicable to spars having received the worst possible treatment. All data resulting from the test are shown and accounted for in the final statistical evaluation. The dangerous practice of deleting a low value as an "isolated occurrence" might lead to a failure in flight which is also an isolated occurrence but unfortunately cannot conveniently be deleted.

A statistical evaluation of the test data was made to show whether or not the testing techniques or the quality of the spars varied with time. The evaluation showed that all specimens and spars were taken from a homogeneous group, or "population," as the statistician would say. This is significant because it shows that the test data are reliable, and, equally important, it indicates that the manufacturing operation is reproducible.

Let us assume now that the design has been substantiated by certain static and fatigue tests and that a set of blades has been produced which are adequate at least for experimental flight. It is a fairly well-established technique then to compare by flight test the actual stresses with figures calculated from the theoretical loads and from this comparison the probable fatigue life can be estimated. In this estimation of life, however, we must be realistic. A specific aircraft may have entirely different flight stresses depending upon the uses to which it is subjected by its operators. How different, for example, is the frequency of application of high accelerations in such operations as vigorous crop dusting and in B.E.A.'s gentle handling of passengers from London Airport to Waterloo Station. With the probable production life estimated at ten years for a design, the blade design must include provision for changes and improvements such as increases in s.h.p, of perhaps 30 to 50 per cent. changes of aircraft gross weight of about 25 per cent. and perhaps even provisions for alternating the rotor diameter, for example, by changing the tip sections or some similar method.

TOO MUCH "SPIT AND POLISH"

There are several types of blades in production to-day whose design life is infinite, yet one blade has an average service life of 160 hours and another has an average of 2,000 hours. This tremendous difference in service life means a considerable difference in cost of operation to the helicopter owner. The frailness of the one blade, which is reflected by the low average service life, is actually responsible for production costs twice that of the more rugged blade. Thus, the initial and replacement blade cost to the operator is higher. Maintenance costs increase because of more frequent blade changes and repairs; and in caring for the more fragile blades, lost time, lost contracts and over-runs are further intangible drains on the operator's pocketbook. A new blade, with all its "spit and polish", goes into service

After a few hours of hovering over sand and gravel, the 10 micro-inch finish is no longer recognisable on that part for which it was specified in order to increase its laboratory endurance limit above measured flight stresses. Obviously, when it is in use, the blade will wear out.

We recently discussed some new blade requirements with a helicopter manufacturer who insisted that we keep our design compatible with his philosophy, which expects an endurance limit of only $\pm$ 8,000 lb. per square inch on a 150,000 lb. per square inch heat-treated steel fitting with moderate built-in stress concentrations. To some, this may sound like poor engineering, but to us, it shows common sense because this part will undoubtedly be subjected to hard wear and tear in service and its failure can mean the loss of life.

Further review of the histories of 20,000 rotor blades have shown the advantages of building-in ruggedness to withstand impact shocks occuring in flight. The very fact that helicopters are versatile causes them to be subjected to flight hazards not normally expected.

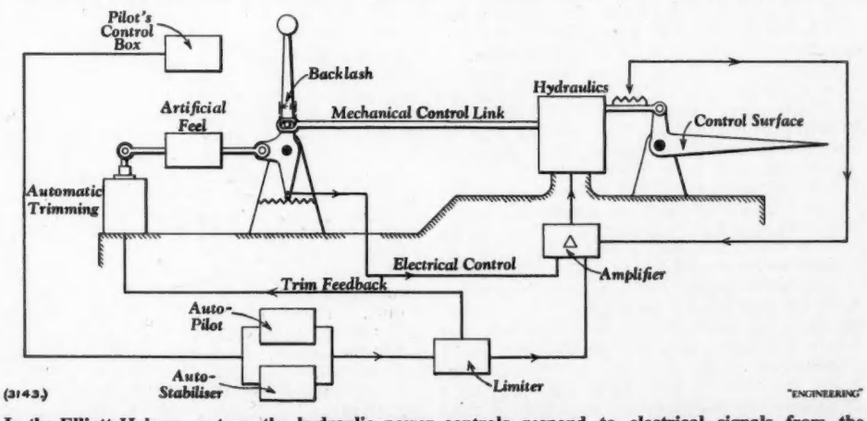
With the military services retiring blades after reaching only a small fraction of their design life, it is apparent that the blades are being lost from service from other causes which include handling damage, shipping damage and the many rotor damage accidents which are caused by operations in confined areas, overloads, etc. The ever-present effort to achieve weight reduction in the blade sometimes boomerangs by creating a product too delicate for the ultimate service to which it will be subjected. The addition of a fraction of 1 per cent. of the blade weight may readily multiply the actual service life of the blade.

INTEGRATED FLYING CONTROL SYSTEM

POWERED CONTROLS LINKED WITH AUTO-PILOT AND AUTO-STABILISER

An integrated flying control system in which hydraulic servos operating the control surfaces respond to electrical signals from the pilot's control column or the automatic pilot, and, in addition, to signals from an automatic stabiliser unit, has been developed by Elliott Brothers (London), Limited, Century Works, London, S.E.13, in conjunction with H.M. Hobson, Limited, Wolverhampton.

The manufacturers claim that the combined power control, auto-stabilisation and auto-pilot facilities offered by the Elliott-Hobson system



In the Elliott-Hobson system, the hydraulic power controls respond to electrical signals from the pilot's control column, the automatic pilot, and the automatic stabiliser. In an emergency the control column can be mechanically linked to the power-control servo-valve.

give improved performance, higher reliability, and greater safety than has hitherto been possible and that the components are fewer and, there, fore, the weight and size of the complete installation is reduced.

An electrical pick-off on the control column gives an output which is balanced by that of a similar pick-off on the output of the hydraulic servo driving the appropriate control surface. Any difference between the two values is amplified and used to control an electro-hydraulic relay which, in turn, operates the first and hence the second-stage hydraulics. Any movement of the pilot's control thus results in a corresponding movement of the control surface.

EMERGENCY DIRECT CONTROL

The control column is also connected mechanically with the valve of the second-stage hydraulics, a limited amount of backlash being provided at the pilot's end. Under normal conditions, the mechanical link is driven by the main power servo and moves so that the control column remains substantially central within the backlash. If the electrical system fails, the pilot has only to operate a simple backlash lock to obtain direct mechanical control of the servo.

Signals from the auto-stabiliser are added differentially in a servo amplifier, and operate the main control surfaces in a similar manner to the electrical signals from the pilot. The stabiliser signals are limited and the control column does not follow the resulting movements, which are taken up in the backlash.

Under automatic control, the control column follows up all control surface movements produced by the auto-pilot. This is achieved by the control-rod run which in this case is rigidly attached to both the control column and the main servo output.

Auto-pilot signals are fed in to the main amplifier in the same way as auto-stabiliser signals and are subject to the same limiting action. This permits signals which are large enough to stabilise the " dutch roll " and both short and long-term pitch oscillations, and allows automatic manoeuvring at high speeds. However for certain auto-pilot functions, the control-surface movements required to trim the aircraft are larger than those which would be safe if applied suddenly as in a runaway.

This difficulty has been overcome by providing automatic trimming and an artificial feel system in pitch, with approximately constant stick force per *g*, operating against a clutch which is arranged to slip at some predetermined force and so disengage the auto-pilot at the desired value of normal acceleration.

RUNAWAY

Although the pilot is provided with a mechanical standby system there is a chance that, in the event of runaway, he may be unable to select this condition due to a rapid increase of acceleration forces. For this reason limit switches and a clutch over-ride have been incorporated.

These operate in the event of runaway while in the auto-pilot or electric control conditions, and control reverts automatically to mechanical signalling without any action being required of the pilot. The system is further arranged to " fail safe " electrically, with automatic reversion to mechanical signalling, and even in the event of sticking solenoids a very low-grade mechanical control is still available. As an additional safeguard, in the latter circumstance, the pilot may be given direct mechanical authority over the solenoid-operated valves which control the backlash lock and declutching arrangement for mechanical operation.

The Elliott-Hobson system is capable of safely applying control-surface angles of the same order as the pilot himself would achieve, and meets the most stringent flight-path control requirements. The following are typical auto-pilot facilities which may be provided: programmed manoeuvres of any desired form within the flight envelope; attitude or manoeuvre holding; miniature stick flying; automatic aiming; and automatic approach and landing.

TURBINES FOR AIR LINERS

DEVELOPMENT AND FUTURE PROSPECTS

The first Albert Plesman Memorial Lecture was given in the Technological University at Delft, Holland, on Tuesday, September 13, by Mr. J. D. Pearson, managing director of the aero-engine division of Rolls-Royce Limited. The subject of Mr. Pearson's lecture was " The Development and Future of Turbine Engines for Airline Aircraft." After outlining briefly the history of the aircraft gas turbine, Mr. Pearson described the development of the first civil propeller-turbine aero engine, the Rolls-Royce Dart—routine development tests, de-icing development, flight endurance tests, fire-prevention tests, component rig tests, high-altitude and cold testing, and metallurgical development. After considering problems inherent to the turbine engine, he discussed service experience with the Dart. He then turned to the performance development of existing engines and, in conclusion, discussed future prospects. We give below an abridged version of Mr. Pearson's written paper, concentrating mainly on the latter part—the immediate development and future prospects of the turbine—but also dealing briefly with the development of the Dart.

The Rolls-Royce Dart propeller turbine is the first aero engine to go into large-scale production for an airline aircraft without substantial prior military experience.

Fig. 1 illustrates some of the factors in its development. Design started in 1945, as a 1,000-h.p. engine for a single-engined military trainer and the first engine ran in July, 1946. Although a type test was completed on this engine in December, 1948, at 1,000 h.p., Rolls-Royce were far from satisfied and commenced a fairly drastic re-design which resulted in the R.Da.3. This went on test in August, 1950, and passed a type test in September of the same year at a rating of 1,400 h.p. This was basically the engine which went into production as the Dart 505 in June, 1952. It will be noted from the chart that approximately 12,000 hours of bench development running were accumulated prior to the delivery of the first production engine.

In Fig. 1, the blocks represent the year-by-year effort in man-hours to manufacture and test the development engines; the top line shows the cumulative total of these hours. The conclusion to be drawn from this experience is that there is a natural gestation period which cannot easily be shortened. Any benefit from past experience and accumulated knowledge is balanced by the fact that each successive engine gets more complicated. One of the factors which experience indicates to be fairly constant is the number of bench development hours required prior to production.

FLIGHT TESTING THE DART

The first Dart engine flew in 1947, as a single engine in a four-engined flying test-bed. This was later augmented by a twin installation in a Wellington, which was later replaced by two engines in a Dakota. By the time the first regular passenger service started in April, 1953, these aircraft had accumulated 1,658 engine hours. Some of this early flying was concerned with the basic problems of controlling a propeller turbine, but the remainder was the routine development flying necessary on any entirely new engine; control problems, calibration of the engine at altitude and at varying forward speeds, fuel system development in flight, de-icing and general behaviour of the engine under all types of flight conditions. It included little straight endurance flying.

The Dart accumulated 14,500 hours of total flying before the first aircraft went into regular passenger-carrying operation. Of this, 9,000 hours—an unusually high figure—were accumulated on the two Viscount prototypes. Both the Viscount prototypes did a certain amount of preliminary route flying. In addition, Dart engines were fitted to two Dakotas which were operated by B.E.A. as freighters and accumulated close to 4,000 hours of flying prior to the commencement of the service. The route flying of the Dakotas by B.E.A. was most valuable because the operation of the engine by an airline brought out troubles not previously uncovered in normal flight testing.

INHERENT TURBINE ENGINE PROBLEMS

It is reasonable to expect that at some time or other a compressor-blade or turbine-blade failure will occur in flight. Such a failure must be contained within the engine and not lead to catastrophic failure. In axial compressors the problem is eased by the use of aluminium blades in the early stages. In the turbine, this, in general means the provision of a sufficiently tough skin around the turbine and for some distance downstream, which can only be determined by test. It also may require an instrument which would enable a pilot to pick out quickly which engine had suffered a blade failure and so to shut it down. On the other hand, experience may indicate that the normal engine instruments will give adequate indication of such a failure.

The centrifugal-compressor rotor comes into rather a different category, but by adequate inspection and corrosion protection, coupled with a thorough understanding of the effect of life on fatigue strength, it should be possible virtually to eliminate such failures in flight. It should also be possible to design engines with centrifugal compressors so that a burst rotor is contained within the engine, by making use of a strong diffuser suitably attached to the main structure of the engine.

One of the most serious failures which could occur would be the bursting of a turbine disc, which could happen either if the engine ran away to the bursting speed, or at normal engine

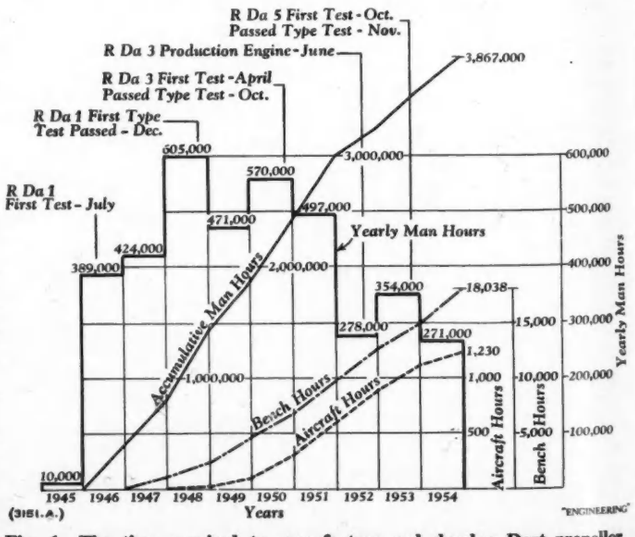


Fig. 1 The time required to manufacture and develop Dart propeller turbines. The blocks represent the year-by-year effort in man-hours to make and test the development engines; the top line shows the cumulative total of these hours.

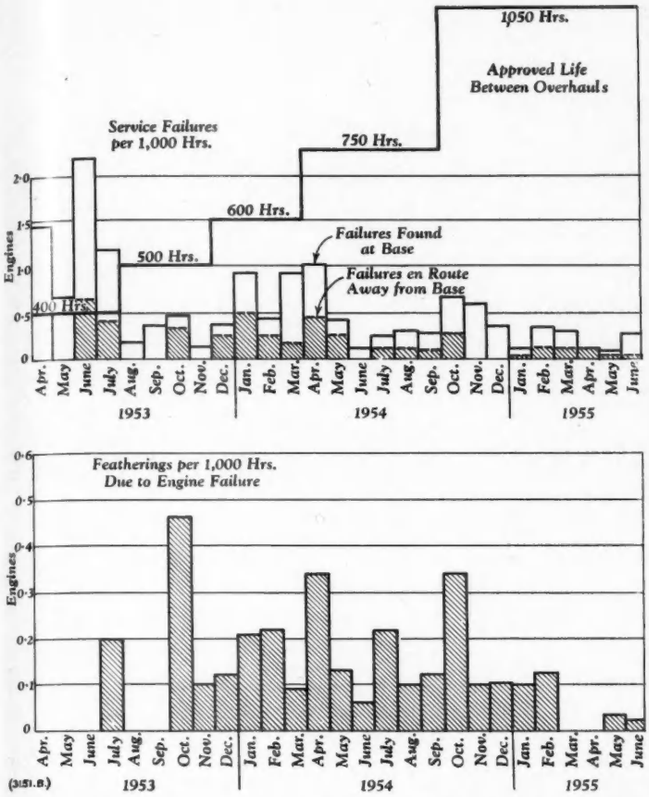


Fig. 2 Failures of the Dart engine in service per 1,000 hours of flying; the top chart also shows the rate at which the engine overhaul life has been increased, likewise plotted on a time basis.

speeds if the disc had an initial defect or developed a defect in service. It is necessary to ensure that the engine will not run away to a dangerous speed under all conditions of internal failure which might occur, such as those which would disconnect the power producing from the power-absorbing sections, or control-unit failures which might put the propeller into fine pitch.

As far as original defects in the discs are concerned, the best known inspection methods must be used and duplicated to avoid any possibility of human error. Ensuring that any defects which develop during service, such as fatigue cracks, do not lead to bursting of the disc, is a difficult but not insoluble design problem.

Proving an engine for the various degrees of over-speeding which can occur with certain types of mechanical or control failure, involves much testing which in many cases must be carried out to destruction. An extensive programme of this nature is one of the essential features of the development of a new civil gas turbine.

SERVICE EXPERIENCE WITH THE DART

Fig. 2 shows statistics of failures of the Dart in service due to engine defects which involve the removal of the engine from the airframe. It also indicates the rate at which the engine overhaul life has been increased, all plotted on a time basis.

There was a crop of minor mechanical troubles with the reduction gear of the sort that only seem to appear when engines actually get into service. Although minor in themselves, these troubles did necessitate removal of the engine and its return for overhaul, and in some cases led to featherings in flight. During this initial period there were virtually no troubles at all with the essentially gas-turbine parts of the engine.

After the initial teething troubles had been overcome, there was relative freedom from trouble until the failures associated with running time began to crop up, in the early part of 1954. One of the chief sources was turbine-blade failure, traced to a resonance at the low-speed end of the running range and aggravated by a slight change in the blade design, the effect of which was not appreciated when it was made. By a combination of dealing with this minor design feature and keeping away from the particular low engine speed where the resonance occurred, this trouble has been virtually eliminated. From that point on, reasonable reliability has been achieved.

The overhaul life of the Dart has been progressively increased from 400 hours to 1,050 hours, although flame tubes are still not up to the full engine life and require one change during that period. There are, however, flame tubes on service trial which should be capable of going through to the full life of 1,050 hours.

The gas-turbine engine poses a new problem in assessing the ultimate life of those major components subject to fatigue, the failure of which could endanger the safety of the aircraft.

In order to assess the ultimate life of components, Rolls-Royce are endeavouring to develop rig tests which will produce typical failures in them and then to repeat the tests on components after various running times in the engine, thus obtaining a measure of the extent to which running time reduces the fatigue life. This procedure is similar to that adopted on propeller blades, the failure of which can be equally lethal.

There is every reason for the overhaul life of the Dart to be extended beyond the present figure, but we are handicapped in doing this by the relatively short life of the longest life-engines, none of which exceeds 2,500 hours. My personal view is that the Dart is doing better than it ought to be doing and that the engine still has some trouble locked away inside it which it is reluctant to reveal.

PERFORMANCE DEVELOPMENT OF EXISTING ENGINES

Propeller Turbines.—The propeller turbine lends itself well to continued performance development, due to its s.h.p. being the difference between the power developed by the turbines and the power required to drive the compressor. Thus any gain in efficiency of these components is multiplied when expressed as a percentage increase in s.h.p. or decrease in specific fuel consumption.

As an example, the Dart turbines develop approximately 4,500 h.p., the compressor takes 3,000 h.p. and the difference of 1,500 h.p. appears at the shaft. This means that a 1 per cent. improvement in turbine efficiency leads to a 3 per cent. increase in s.h.p and a 3 per cent. decrease in specific consumption, and that a 1 per cent. improvement in compressor efficiency leads to a 2 per cent. increase in s.h.p. and a 2 per cent. decrease in specific consumption.

Improvements can also be effected by raising the cycle temperature. In general both tend to be done concurrently and as an example Fig. 3 shows what has been done with the Dart. The reward obtained for a particular engine design by being able to operate at higher flame temperatures is shown in Fig. 4. The intensive development now proceeding on air-cooled turbine blades and air-cooled nozzle guide vanes will lead to continuous performance development of existing propeller turbine engines for some time to come.

Jet Engines.—The picture for the performance development of existing jet-propulsion engines is rather different. Although the thermodynamic efficiency of the cycle still increases with increasing temperature, this is more than off-set by the decreasing propulsive efficiency of the jet. Thus, with the simple jet engine, the optimum specific fuel consumption is obtained at a much lower flame temperature at subsonic forward speeds than that at which the engine must be designed to obtain a good thrust/weight ratio.

This means that the specific consumption of the jet engine cannot be improved by developing the engine to use increased flame temperature. This still leaves open the possibility of improved specific consumption by improved efficiency of components and by raising the compression ratio. The latter can be accomplished either by adding stages to the front or the rear of the compressor. If to the front, then the mass flow is raised at the same time as the compression ratio, if to the rear, only the compression ratio is increased. On a particular engine which has been developed as a military engine to give the maximum possible thrust, the specific fuel consumption has been reduced by 8 per cent. by these methods.

The by-pass engine is a sort of "half-way house" between the propeller turbine and the straight jet engine, and, in fact, it comes into existence as an attempt to counteract the falling propulsive efficiency with increasing temperature of the straight jet engine. Here, the optimum temperature for best specific fuel consumption is higher than on the straight jet engine, but is dependent on the by-pass ratio. It can take advantage of the higher cycle efficiency by operating at a higher turbine inlet temperature, combined with an improved propulsive efficiency derived from a lower jet-pipe temperature. This gives the by-pass engine its advantage in specific fuel consumption over the straight jet engine.

REVERSE THRUST

With a piston engine it is necessary to reverse the pitch of the propeller and run the engine to obtain significant drag. A single-shaft pro-

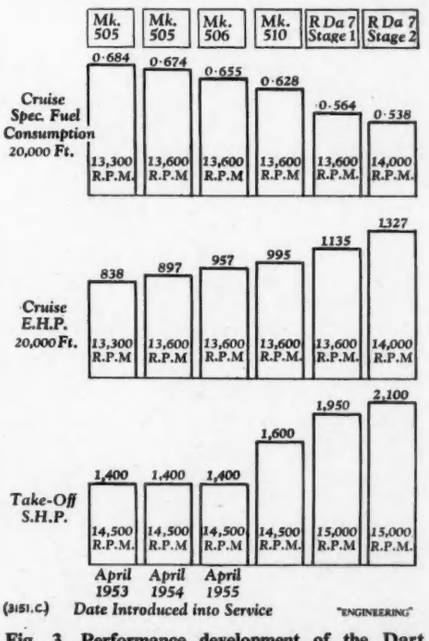


Fig. 3 Performance development of the Dart engine; both raising cycle temperature and increasing compressor and turbine efficiency have led to the improvement.

peller turbine handles a large amount of excess air (six times as much air as a piston engine with the same power) and so has a large pumping power consumption. Thus, by allowing the propeller to windmill and drive the compressor, a very considerable amount of drag is available. This is what happens on the Dart, which provides a significant reverse thrust during the high-speed part of the landing run, but, of course, provides but little reverse thrust when the aircraft slows down. However, it appears to represent a reasonable solution for aircraft of the size powered by the Dart. With two-shaft propeller turbines, in which the propeller is connected to only one of the shafts, the drag available is reduced and this type of engine will require a reversing propeller, thus following present piston-engine practice.

On the jet engine, reverse thrust can only be obtained by physically deflecting the jet into a forward direction. Full reversal would be undesirable as the engine would tend to breathe its own exhaust gases. It would seem that 45-deg. reversal would be adequate as this permits up to 70 per cent. of the rated engine thrust to be obtained in reverse. To effect the change of direction of the exhaust gases, some substantial mechanism is required as the forces involved are quite considerable.

The use of adjustable reverse thrust opens up some interesting possibilities; it should enable the engine to be run at full r.p.m. so as to provide the maximum services for anti-icing and flap blowing and at the same time control the net thrust on the aircraft by adjusting the reversing nozzle. Such an arrangement also opens up the possibility of making a landing approach with all engines running at full power, so that if the aircraft has to go round again, full forward thrust is available immediately by merely moving the reverse-thrust eyelids and without having to wait for the engines to accelerate. The possible uses of such a system on military aircraft are obvious and this development is going ahead. It is close to being an essential feature for the operation of large jet aircraft.

INCREASING COMPLICATION

Nature shows us that improved adaptation to the environment leads to complication. This is certainly true of the turbine engine. In order to get improved consumption, higher compression ratios must be used and, to obtain these at reasonable compressor efficiencies, it has been necessary to desert the relatively simple centrifugal compressor for the axial compressor and then to go to a two-shaft design to get satisfactorily up to the highest compression ratios.

On the turbine side the demands of increasing efficiency have led to multi-stage turbines. The various sealing arrangements through the engine have become increasingly complicated in the interests of reducing leakage losses.

On the fuel-system side a successful rearguard action is at the moment being fought against further complication by the introduction of "black boxes" interposed between the pilot's lever and the engine and propeller, but eventually some sort of compromise may have to be incorporated even on this.

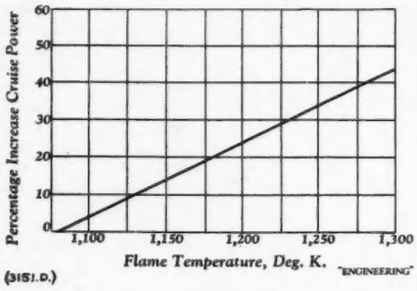


Fig. 4 Effect of flame temperature on the cruising power of a propeller turbine.

We at Rolls-Royce often look back with incredulity to the time when the Derwent engine was designed in two months and running five months after the design began. As a simple example of this unfortunate but inevitable process, the Derwent engine had 9,000 parts, the Dart 12,000 and the RB.109 has 20,000. This increased complication has been enforced by the endeavour to make the engine meet more suitably the requirements of better fuel consumption, less frontal area and less weight.

Fig. 5, which shows the Dart and the RB.109 side by side to the same scale, is an interesting example of the rapid progress of design. The RB.109 will give very nearly three times the horse-power that the Dart gave when it first went into service, although of the same overall diameter and weighing only 50 per cent. more.

POWER AND R.P.M.

The piston engine seemed, by nature, to have a happy relationship between power and r.p.m. at take-off, climb and cruise, which suited the speeds of the aircraft to which they were fitted, at least until quite recently, and gave a combination of acceptable durability and a reasonable propeller tip speed for cruise. These relationships require re-examination as aircraft speeds increase on propeller-turbine driven aircraft. One of the fundamental differences between the piston engine and the gas turbine is that the compression ratio of the latter, which is still the basic factor affecting fuel consumption, falls with falling engine r.p.m., with the result that, from the engine efficiency point of view, the cruise r.p.m. should be as high as possible. This unfortunately cuts right across the requirements for low propeller noise.

Tests recently carried out have demonstrated that propeller noise is a rapidly increasing function of helical Mach number, which makes the problem more difficult for fast propeller-driven aircraft.

Strenuous efforts must be made in the design of the engine to obtain the maximum possible spread in r.p.m. between take-off and cruise without sacrificing specific consumption. The best that can be done at present will not give as big a spread in r.p.m. as normally exists on piston engines, unless a free power turbine is used, but this has other disadvantages for high compression engines.

If a reduction-gear ratio and propeller diameter are chosen to give an acceptable helical tip Mach number from the noise point of view, then compared with present-day piston-engine practice the propeller will be turning too slowly for take-off. Fortunately, the requirements of high forward speed lead to engines of a power which, by piston-engine standards, give excess power for take-off. This means that in aircraft which cruise at high speed there will always be plenty of horse-power available for take-off.

The limitation in take-off thrust will then be in the propeller itself, because at a given r.p.m. a given propeller can usefully employ only so much horse-power. Thus the engine designer will then be brought under pressure to overspeed his engine at take-off, which he will resist for obvious reasons.

For certain long-range aircraft, where the restriction on take-off run is not so great as for short and medium-range aircraft, the excess power available at take-off may lead to engines which are virtually throttled at take-off. In fact, as the power of existing propeller turbines is increased there will be a general tendency for this to happen when increased cruising speed is the important requirement.

These considerations apply essentially, of course, to four-engined aircraft. For twin-engined aircraft the excess power available is usually welcome in order to satisfy the requirements for single-engine take-off and climb, and to enable the aircraft to use shorter runways.

TURBO-PROP VERSUS TURBO-JET

We have already seen the public in America show a definite preference for speed at the expense of noise in the newer and faster piston-engined transports. We have also, in the case of the Viscount, seen the public show its preference for comfort. I believe that the jet transport will have a greater passenger appeal over the turbo-propeller transport on both counts, and that we shall increasingly see the jet transport, when it is re-established, invade the propeller-turbine field, certainly for first-class travel, always provided that the airport noise of jet transports can be brought down to a level which is acceptable to the public.

Apart from noise considerations the limit of the invasion of the turbo-propeller field will clearly be determined by the overall economies, taking into account the effect on load factor of passenger appeal, as well as the seat-mile cost. It seems unlikely that the straight jet aircraft will come into the short-range picture within the foreseeable future, but it is probable that there will be some invasion of the medium-range field. In the long-range field the turbo-propeller will have to fight hard to retain its place by providing very much cheaper seat-mile costs.

THE NEXT FIVE YEARS

Propeller Turbines.—The next five years will undoubtedly see the emergence of the high compression-ratio two-shaft propeller turbine, which, with its improved fuel consumption, will tend to make existing single-shaft engines obsolete.

The rival virtues of high and low compression ratio are much the same in propeller turbines as in reciprocating engines. Heavy road vehicles

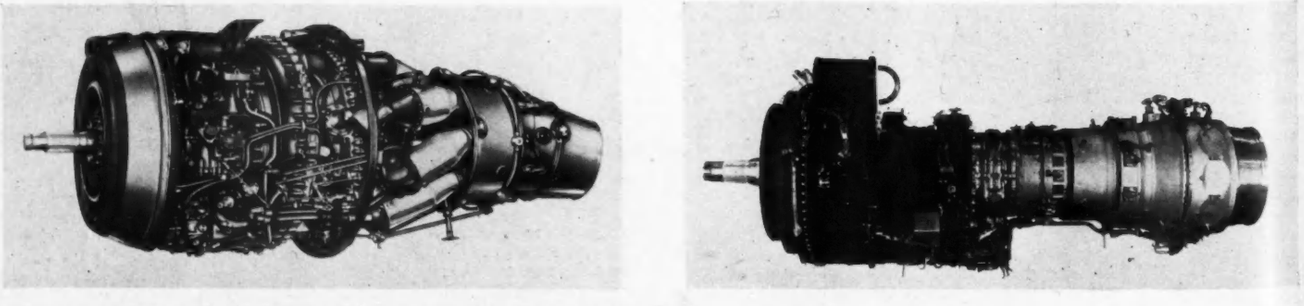


Fig. 5 The R.B. 109 (right) develops nearly three times the power of the Dart (left) although of the same overall diameter and weighing only 50 lb. more. The two engines are shown here to the same scale.

have gone over to the high compression-ratio Diesel engine in the interests of fuel economy, but the medium sizes are slow to change and the smallest have not changed. Civil aircraft will probably use high compression ratio in only the larger sizes for the same reasons, which are that well-established and low-cost small engines exist, that the emphasis on fuel consumption is not so great over the shorter distances over which the smaller engine will be used, and that first cost is normally more important in the application of the smaller engine. Just as the petrol engine has progressively increased its compression ratio to narrow the gap between it and the Diesel engine in the smaller sizes, so the single-shaft propeller turbine will undoubtedly continue to improve its efficiency.

It is safe to predict that aircraft designers will welcome increased powers from existing engines. Aircraft speeds will increase and new aircraft will be designed to start off with a significant speed margin over the types they are designed to replace. This period should see the introduction of medium and long range turbo-propeller aircraft and the introduction of twin-engined turbo-propeller aircraft, of which a typical example will be Holland's Fokker Friendship.

The turbo-propeller is particularly suitable for fast twin-engined aircraft because of the low power-plant weight, coupled with the relatively high powers which will be available for take-off and climb. These technical features, coupled with the increased reliability, may lead to a revival in popularity of the twin-engined aircraft where cost of operation is paramount. It is even possible that turbo-propellers may result in the development of what has almost become a legendary aeroplane, the DC-3 replacement.

If helicopters are going to play any significant part in air transport then there is little doubt that the gas-turbine engine will be the power plant.

Jet Engines.—Numbers of jet engines which are currently under development for military purposes should be available for civil use during the next five years, and the civil aircraft designer should have a considerably wider choice than he has with propeller turbines. Whereas, however, new propeller turbines are being developed specifically to suit a particular type and size of civil aircraft, in jet engines the civil aircraft man will have to take what is available. There is little possibility during the period under review of a brand new jet engine specifically designed for civil operation coming into service.

It seems that civil engine requirements of the larger aircraft during this period can be met by a number of straight jet engines now in an advanced stage of development or in production in the 10,000lb. to 15,000lb. thrust class. As the makers of the only large by-pass engine in the world, the Conway, we believe that this engine will find its place in those aircraft which are of a size to require an engine of the Conway's thrust.

As far as aircraft are concerned, this period should see the introduction into service of both medium and long range jet transports.

THE LONG TERM PICTURE

The path ahead for the propeller turbine is, from a technical point of view, straight-forward: improving the overall efficiency by increased efficiency of components and development to permit higher flame temperatures, together with a continuing reduction in specific weight by getting more power out of the same size of engine. How far down the scale of size the two-shaft axial engine can profitably be carried is a debatable point.

Far more important from the engine manufacture's point of view—where will the jet engine take over from the turbo-prop? As mentioned previously, my own feeling is that by force of public preference the jet engine will invade the turbo-propeller field.

There is no sign of a slackening in military demands for more jet power at higher speeds and the pace is likely to be governed by the pace of military developments.

The problems of supersonic transport are enormous, but that is only a good reason for getting started on them. When the aircraft manufacturers and the operators are ready for supersonic civil transports, the engine industry will certainly be ready with suitable engines, both to propel them and, if necessary, to lift them off the ground.

HEATING OIL CARGOES

STEEL PIPES WITH CAST-IRON SLEEVES

The growth of the world's tanker fleets has been continuous for a number of years, and particularly rapid since the second World War. One of the problems in transporting oil cargoes is to keep the oil sufficiently fluid to be handled by the pumps. This is normally done by steam heating, passing steam through coils in the oil tanks. The main requirements of such installations were discussed in an article " Steam heating using aluminium alloy pipes " (ENGINEERING, July 29, 1955, vol. 180, page 151); the transmission of heat through the pipes must be efficient, the pipes must resist corrosion, and the installation as a whole must be robust enough to stand the shocks experienced when the ship is at sea.

The corrosion-resistant qualities of cast-iron have been proved in fuel economisers over the last 100 years, particularly in the range 100 to 250 deg. F. Cast-iron is also cheaper than other materials used for heating coils. Great care is needed, however, in the alignment and fixing of cast-iron pipes, and even then the working of the ship's structure combined with the movement of the pipes themselves as the temperature varies are prone to cause breakages and leaks.

The firm of E. Green and Son, Limited, Wakefield, has developed a system using steel pipes with cast-iron sleeves. The flexibility of the steel is thus combined with the corrosion-resistance of cast-iron, and the sleeves have been designed for the greatest efficiency in heat transmission. The form of the sleeves can be seen in Fig. 1, which also shows how they have been designed so that they can be easily cleaned. It is claimed that the heat transmitted to the oil per unit of external surface is slightly greater than that obtained with plain tubes, probably because the projection of the heating gills into the liquid assists in the formation of stronger and unresisted upward convection currents.

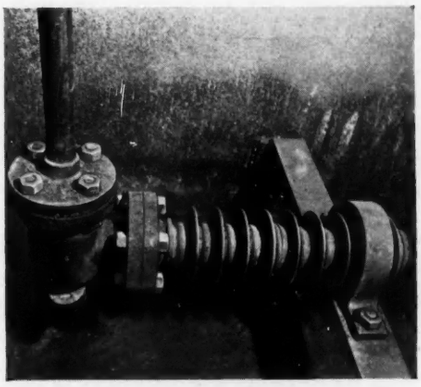


Fig. 1 The heating coils consist of steel pipes with cast-iron sleeves. The sleeves are designed for efficient heat transmission and easy cleaning. The drain pot is constructed to ensure practically continuous discharge of condensate.

The system uses steam flow in parallel through the oil tanks, making for more efficient use of the steam than when it passes through pipes in series. Part of the general layout can be seen in Fig. 2, where the connections of three pipes to the exhaust header are shown. In this continuous drainage system the individual pipe-runs extending fore and aft in each tank are connected in parallel to a steam inlet header attached to the forward bulkhead, the pipes themselves being arranged to fall slightly towards the drain pots fixed at the after end of each pipe run. Each drain pot (one of which is shown in Fig. 1) carries a dip pipe extending close to the bottom of the drain well, and the size of the dip pipe is so proportioned to the main pipe bore that condensate water only and not steam is discharged. The outlets from the drain pots are connected to a common discharge or exhaust header with a single outlet up to the deck trap or return line.

In this way waterlogging of the system is prevented; the discharge of the condensate as it accumulates in the drain pots is practically continuous, and since the pipes themselves are always kept clear of water, the heat transfer is maintained at a steady rate. It is possible therefore to reduce the steam flow, or to cut down the total heating time, but in either case there is an appreciable saving in steam.

To make an approximate comparison, the basis of present practice is to allow the same external heating surface as for a plain pipe system. The weight per square foot of surface, allowing for supports and all ancillary material, averages about 13lb. As a result, the total weight and cost are appreciably less then the equivalent cast-iron system, and installation is somewhat simpler.

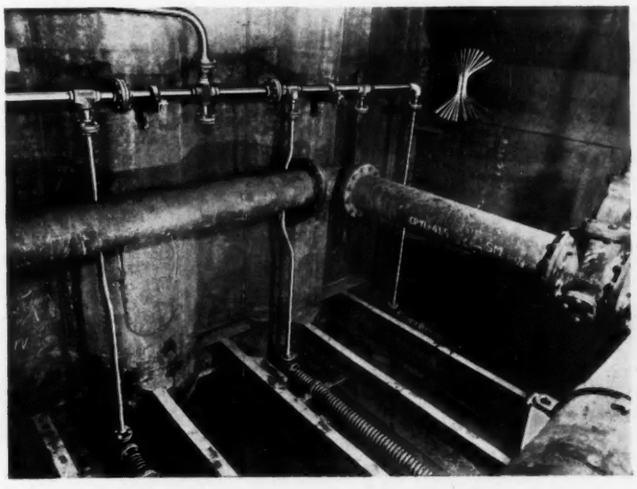


Fig. 2 Heating coils at the bottom of an oil tank. Steam flow is in parallel from the inlet header to the exhaust header, which is shown here.

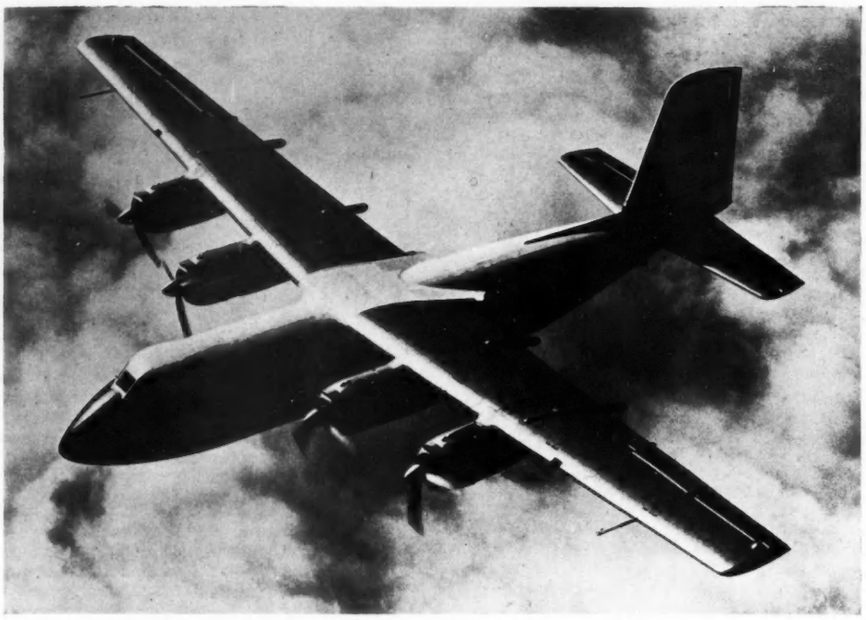


Fig. 7 Herald branch liner: Handley Page Limited.

THE AIRCRAFT INDUSTRY DISPLAY

(2) CIVIL AIRCRAFT AND HELICOPTERS

The Vickers-Armstrongs Viscount air-liner, powered by the admirable Rolls-Royce Dart propeller turbines, has continued to maintain its promise by capturing further overseas markets—a total of 236 are now on order for air lines in Great Britain, Eire, France, Australia, Canada, U.S.A., West Indies, Iraq, India, Egypt, Hong Kong, Burma and Holland, and also for several American companies—though it must be admitted that events of the past two years seriously set back the British aircraft industry's hopes for gaining its supremacy in supplying the world's air lines.

The Comet air-liner disasters, concluded to be due to cabin fatigue failures, not only reduced a large part of the lead the de Havilland Aircraft Company, Limited, had achieved, but they have also to some extent weighted the scales against other British high-altitude air-liners, for this reason: the Air Registration Board will not now grant a certificate of air-worthiness unless a whole airframe of a new type has satisfactorily withstood a load-cycling test in a rig designed to reproduce the variations of cabin pressure and wing loading experienced during repeated take-offs, cruising flight and landings. This is a lengthy and costly process. At present, no such test is demanded by the corresponding licensing authorities in America, and therefore, in overseas markets, new American air-liners are likely to start with an economic advantage, though technically they may be less comprehensively proved.

BRITANNIA

The first phase of the airframe fatigue-testing programme on the Britannia air-liner, constructed by the Bristol Aeroplane Company, Limited, Filton, Bristol, was completed a few weeks ago in the water-tank rig at Farnborough, and the results are now being evaulated. The version known as the Britannia 100, which is expected to go into service on British Overseas Airways Corporation's South African routes next spring, appeared in the flying display. This aircraft, powered by four 3,780 e.h.p. Proteus 705 propeller turbines, carries 63/90 passengers and, cruising at a speed of 340 m.p.h., has a still-air range of about 3,700 statute miles with full payload; with fuel tanks full, and a payload of 12,250 lb., the maximum still-air range is about 5,100 miles. (These ranges make no allowance for fuel reserves.)

The long-range versions developed from the Britannia 100 were on view in model form in the static exhibition—the 65/93-passenger Britannia 300 LR, 11 of which have been ordered by B.O.A.C. and three by El Al (Israel Airlines), with an option on two more; and the Britannia 250 LR, a general-purpose cargo/passenger machine with accommodation for 60/84 passengers, three of which have been ordered by the British government for troop carrying. Both long-range versions are powered by four 4,120 e.h.p. Proteus 755 propeller turbines, have longer fuselages and an increased fuel capacity and cargo space, and have a maximum stillair range of about 6,200 miles with a payload of 16,300 lb. With full payload, 28,000 lb., the range is over 4,900 statute miles. Thus the long-range Britannia can make the North Atlantic crossing without refuelling stops all the year round.

COMET

Although, as we have already said, the de Havilland Aircraft Company, Limited, Hatfield, lost a lot of the ground that they had gained in the civil airliner race, they are still the only manufacturers in the world with a background of commercial operating experience on jet aircraft. In order to expedite the flight-testing of the new Comet 4 air-liner, which is not likely to fly before 1957, the company are carrying out an intensive flight-test programme on the Comet 3 prototype, which again appeared in the flying display at Farnborough. The Comet 3 has now completed some 150 hours of flying, and its performance has been measured; from these figures, the performance of the Comet 4—which has the same dimensions—has been predicted.

The general particulars of the two aircraft are as follows: span, 115 ft.; length, 111·5 ft.; height, 28·5 ft.; wing area, 2,121 sq. ft. The four Rolls-Royce Avon R.A.29 engines of the Comet 4 will each deliver a static thrust of 10,500 lb., as against 10,000 lb. on the R.A.26 Avons installed in the Comet 3. The all-up weight of the Comet 3 is 150,000 lb.; that of the Comet 4, 152,500 lb.; and the respective fuel capacities are 8,360 and 8,760 Imperial gallons. The accommodation offered by the Comet 4 is 58-62 first-class or 71-76 tourist-class passengers; a mixed-traffic version accommodating up to 59 passengers is also offered. The cruising altitude for both aircraft is 42,000-45,000 ft.

On the basis of the Comet 3 tested performance, the Comet 4 is expected to be able to carry its volumetric first-class payload, 16,400 lb., over a stage length of 2,900 statute miles—this allows for the necessary fuel reserves for diversions, descent, stand-offs, etc. Carrying the maximum tourist payload of 19,300 lb., the stage distance is 2,700 statute miles. Thus the Comet 4 will be capable of operating non-stop, at a cruising speed of slightly more than 500 m.p.h., over the majority of the world's busiest trunk routes.

HERALD BRANCH LINER

Among the smaller commercial aircraft, the well-established 14-17 seat de Havilland Heron, now equipped with de Havilland feathering propellers, demonstrated that it can take off on three of its four Gipsy Queen engines and cruise happily on only two. There were two transport newcomers—the Twin Pioneer, designed and constructed by Scottish Aviation Limited, Prestwick, and the Herald, designed and constructed by Handley Page (Reading) Limited, Woodley, near Reading.

The Herald " branch liner," Fig. 7, above, described in the September 10, 1954, issue of ENGINEERING (vol. 178, page 350), is intended as a " D.C.3 replacement " for operating from airfields where the facilities are not of the standards found on international airports, over short to medium stages. It provides accommodation for 36 first-class or 44 tourist passengers plus cargo.

The Herald is powered by four 870-h.p. Alvis Leonides piston engines, chosen rather than propeller turbines because airline maintenance engineers of the out-back regions are not yet familiar with the ways of gas turbines. The aircraft is pressurised to a maximum differential

Fig. 8 Twin Pioneer feeder liner: Scottish Aviation Limited.

Fig 9. Accountant fuselage, constructed on the Heal pre-tensioned method: Aviation Traders (Engineering) Limited.

of 3·35 lb. per square inch, so that passengers can be flown comfortably at 15,000 ft. altitude and higher. The tricycle undercarriage is retractable and Fowler flaps are fitted, enabling the aircraft, fully laden, to take-off or land over a 50-ft. obstacle in less than ½ mile. Flaps and undercarriage are hydraulically operated. There is provision for de-icing the wings and tail surfaces.

The all-up weight of the Herald is 34,000 lb. and the normal fuel tankage 700 gallons, but there is space for increasing the tank capacity to 1,000 gallons. It is expected to cruise at between 190 and 200 m.p.h. at 10,000 ft. The span is 95 ft., the overall length 70 ft. 3 in., and the height 22 ft. 6 in.

Already 29 orders have been placed for the Herald—by Australian National Airways, Queensland Airlines (in whose colours the prototype was demonstrated at Farnborough) and Lloyd Aero Colombiano in South America.

TWIN PIONEER

The Twin Pioneer, illustrated in Fig. 8, should make an important contribution to the solution of the transport problems of the outback areas, to which the Duke of Edinburgh called attention last year in the Tenth British Commonwealth and Empire Lecture (summarised in the December 24, 1954, issue of ENGINEERING).

Designed for economic and simple operation from landing grounds of limited size, the Twin Pioneer embodies the experience gained in the use of high-lift devices in the Prestwick Pioneer, which has now regularly demonstrated its exceptional take off and landing abilities at Farnborough for some years.

The all metal Twin Pioneer, powered by two 550 h.p. Alvis Leonides 503/8 engines, offers accommodation for 14–16 passengers and baggage, and for a crew of two—although the aircraft can be operated by one pilot alone. The wing area is 657 sq. ft.; span, 76 ft. 6 in.; length, 45 ft. 1 in.; and height, 13 ft. 8 in.

The high-lift devices which give the Twin Pioneer its outstanding take-off and landing performance comprise hydraulically-operated leading-edge slats on the outer wings (the centre wing has a fixed slat) and Fowler trailing-edge flaps extending over 30 per cent. of the wing chord and over 70 per cent. of the span, with a maximum deflection of 30 deg. for landing; a 12 deg. setting is used for take-off. These give, in effect, a very highly cambered wing.

Under international standard atmosphere conditions the distance required to take-off and clear a 50 ft. obstacle, at the maximum take-off weight of 13,500 lb., is less than 360 yards on a grass airfield. The landing distance over a 50 ft. obstacle is less than 300 yards, the actual landing run being less than 140 yards. The stalling speeds, engine off, are 67·5 m.p.h. with flaps retracted, 51·5 m.p.h. with flaps 12 deg. down, and 47·5 m.p.h. with flaps fully down.

The cruising speed at 40 per cent. take-off power at 5,000 ft. is 124 m.p.h.; the still-air range at this speed, with full fuel tanks (160 Imperial gallons), is 620 statute miles, with a corresponding payload of about 3,000 lb., made up of 16 passengers and 440 lb. of baggage and cargo. Increasing the cruising speed to 139 m.p.h. reduces the still-air range to 565 miles.

Watching the Twin Pioneer take to the air and climb steeply away gives rise to speculations on the possibility of developing such machines for inter-city transport, in place of the expensive and complex helicopter. By suitable routing, it might be possible to operate from small airstrips or water bases in the city centre without excessive demands on valuable city space.

ACCOUNTANT FUSELAGE

Another versatile D.C.3 replacement, expected to fly next year, is the 12/36-seat Accountant, powered by two Rolls-Royce Dart RDA6 propeller turbines, designed to cruise at about 280 m.p.h. over stage lengths ranging from 200 to 1,570 nautical miles. The fuselage of this aircraft, which is under construction by Aviation Traders (Engineering), Limited, Southend Airport, and which employs a new form of construction invented by the company's chief designer, Mr. L. C. Heal, was on view at Farnborough. It is designed for a pressure differential of 5½ lb. per sq. in. In Fig. 9 the fuselage is shown under construction in the experimental shop at Stansted. On the left is shown the simple type of assembly jig required.

A description of the Heal method of pre-tensioned construction for double-curvature fuselages of circular cross-section was given in the September 4, 1953, issue of ENGINEERING (vol. 176, page 311). The Accountant fuselage, constructed on these principles, consists of a symmetrical assembly of ten longitudinal panels of 22 s.w.g. L72 light alloy sheet. The panels, identical, are cut together and drilled in the flat from a single template. They are lightly edge-stiffened, and assembled to transverse circular frame segments, of pierced sheet formed to a channel section. The next stage is forming the stiffened panels to the longitudinal curvature by stretching over a simple frame, and in so doing introducing a tensile stress into the skin; while on the former the panels are assembled into half fuselages. The method is simple and economical, and it is claimed to give the required strength and stiffness with a marked reduction in weight, as compared with conventional built-up construction methods. It also results in a smooth skin surface free from waviness.

Since economy in construction is one of the principal attractions of this technique, high-strength materials have not been adopted. The policy has been to work to low stresses, and the mean skin tension introduced into the skin panels does not exceed 7,000 lb. per sq. in.

HELICOPTERS

Two new helicopters took part in the flying display—the Westland Widgeon and the Fairey Ultra-light helicopter. The Widgeon, has been developed from the well-known S51 by Westland Aircraft, Limited, Yeovil, as a general-purpose helicopter with accommodation for five persons, or as an ambulance machine, or for rescue duties with a winch on the starboard side visible to the pilot.

The Widgeon is powered by a 550 h.p. Alvis Leonides engine, and employs transmission components of proved performance; it has the same type of rotor head as used on the latest Whirlwind S55 helicopters. This, it is claimed, eliminates susceptibility to movements of the centre of gravity, and there is no need to carry ballast weights compensating for load variations.

The main three-blade rotor has a diameter of 49 ft. 2 in., and the tail rotor is 8 ft. 5 in. in diameter. The fuselage is 41 ft. 2¾ in. long; the height to the top of the rotor pylon is 12 ft. 11⅜ in., and to the top of the tail rotor, with blade vertical, 12 ft. 8 in. The cabin is 6 ft. 3 in. long 4 ft. 3 in. high and has a maximum width of 4 ft. 10 in. The floor area is 24¼ sq. ft. As a passenger machine, the seating is arranged two forward and three back, all seats being of the individual type. In the ambulance version, two stretchers are accommodated, one above the other, on the port side, a clam-shell nose in the door facilitating loading. The medical attendant is seated behind the pilot. Conversion from passenger to ambulance aircraft is quickly and simply carried out.

Fully loaded, the Widgeon weighs 5,900 lb. It cruises at 70 knots at sea level and has a maximum range, with no allowances made for necessary fuel reserves, of 260 nautical miles. With the full passenger payload, it has a range of about 100 nautical miles. The service ceiling is 10,500 ft., and the hovering ceiling is 7,500 ft.

The Ultra-light helicopter flown by the Fairey Aviation Company, Limited, Hayes, Middlesex, was designed to fulfil a War Office specification for a two-seat air observation post. Seated in a transparent cockpit, the observer can be seated facing forward beside the pilot, or his seat can be reversed so that he faces aft. The transparent cockpit is carried on a tubular framework mounted on skid landing gear. The engine—a Blackburn-built Turboméca Palouste

Fig. 10 The Ultra-light helicopter: The Fairey Aviation Company Limited.

Fig. 11 The Jet Gyrodyne: The Fairey Aviation Company Limited.

turbo-compressor—is housed at the rear of the fuselage framework, the jet pipe cantilevering aft. A rudder to give directional control is suspended from a short outrigger.

The Ultra-light has a two-blade rotor, reaction-driven by pressure jets at the rotor blade tips to which compressed air is supplied by the Palouste compressor. It is said to be very pleasant to handle owing to the " fly-wheel " effect conferred by the tip-drive arrangement, and to the absence of yawing effects. It is the smallest helicopter yet built in Great Britain—it can be transported in a 3 ton truck, or with porter bars inserted in the undercarriage cross-tubes it can even be shifted by hand, as shown in Fig. 10, on the previous page.

The Fairey company also flew the Jet Gyrodyne (Fig. 11) which they have been using for tests into problems of tip jet propulsion and for proving the rotor head destined for the Rotodyne. The 550 h.p. Alvis Leonides piston engine of the Jet Gyrodyne is arranged either to drive compressors feeding air to pressure jets at the tips of the two-bladed rotor, or, in cruising flight, to drive two pusher propellers installed on the stub-wing tips. The transition from rotor-borne helicopter flight to propeller-drive cruising flight was demonstrated for the first time in Great Britain, and the machine made an auto-rotative landing.

Among the more familiar helicopters flown, the Gipsy Major-powered Skeeter Mark 6 constructed by Saunders-Roe Limited, Eastleigh, has been ordered by the Royal Air Force and is now in production; and a development of the tandem-rotor Bristol 173, the type 191, is being constructed by the Bristol Aeroplane Company, Limited, Filton, for anti-submarine duties with the navy. It is powered by two 850 h.p. Alvis Leonides Major engines, has a slightly shorter fuselage than the 173 for stowage on aircraft carriers, and a redesigned undercarriage. This machine was on view in model form in the static exhibition.

Also on view in the static exhibition was a model of the 10 passenger P.105 helicopter project of Hunting Percival Aircraft Limited, Luton. In this design, the main rotor and Napier Oryx turbo-gas generators are arranged to form a single, compact unit, complete with an auxiliary gearbox and tail-rotor drive shaft coupling. The fuselage, forming a separate component, is then suspended beneath the rotor-generator unit. This arrangement allows freedom of fuselage design, which is of particular importance in view of the many varied roles in which the helicopter may be required. The main structure of each blade is of stainless-steel spot-welded construction, with a light-alloy tail fairing. Each blade is terminated at the tip by a cascade, which forms the jet nozzle.

Other aspects of the Farnborough Show will be considered in subsequent articles.

EQUIPMENT FOR TESTING INVERTERS IN AIRCRAFT

The accompanying illustration shows equipment which has been designed by Messrs. Arthur Lyon and Company (Engineers), Limited, 6 Carlos-place, London, W.1, for testing the inverters installed on aircraft during periods of overhaul. It consists of a framework of angle construction with louvered steel covers, which totally enclose the unit, and a table, 24 in. wide, by 26 in. long, 42 in. above floor level. As will be seen the instruments and their associated switches are mounted above this table at eye level.

On the direct-current, or input, side these instruments consist of a moving-coil voltmeter with ranges of 0 to 30 and 0 to 150 volts and a moving coil ammeter with ranges of 0 to 10, 0 to 100 and 0 to 200 amperes. These ranges are brought into use by appropriate switches which, in the case of the ammeter, connect or disconnect the shunts as required. The direct-current input is obtained through two terminals on the side of the tester which are capable of carrying up to 150 amperes.

The instruments on the alternating-current, or output, side consist of a moving-iron voltmeter with a range of 0 to 150 volts which is suitable for use on frequencies from 300 to 3,000 cycles. The moving-iron ammeter is designed for the same range of frequencies and for measuring currents between 0 and 50 or 0 and 25 amperes. There is also a triple-range dead-beat frequency meter with coil spring control and with three external bridge network boxes, so that ranges from 360 to 440, 1,440 to 1,760 and 2,160 to 2,640 cycles are obtainable by operating a switch. Below the test table is a switch which enables the voltage of any pair of three-phase lines to be read, while a current transformer and further switch are available for ascertaining either single or three-phase loads or the loads in any one of the three-phase lines.

This equipment is for testing inverters installed in aircraft; inverters are used to change direct current to alternating current.

THREE-PHASE LOAD

The three-phase load is provided by an open type resistance on which there are tappings enabling 2,000 watts, 1,000 watts, 500 watts and 250 watts to be imposed at 115 volts. With this is associated a variable reactor with a total resistance of 266 ohms, which is operated by a hand wheel on the front of the board and is designed for a current range of 0·25 to 1·25 amperes giving a maximum loading of 16·7 watts per phase when connected in star across the 115 volt alternating current supply.

There are a similar resistance and variable reactor for providing the single-phase load. These have resistances of 266 and 202 ohms respectively, the latter being arranged so that the load can be reduced to a minimum of 50 watts at 115 volts.

The tester is provided with two fixed and two swivel casters for easy transportation. The input and output terminals are enclosed to prevent external contact.

* * *

LAUNCHES AND TRIAL TRIPS

S.S. " HINEA."—Single-screw oil tanker, built and engined by Vickers-Armstrongs Ltd., Barrow-in-Furness, for Shell Tankers Ltd. (Marine Managers for the Anglo-Saxon Petroleum Co., Ltd.), London, E.C.3. Main dimensions: 555 ft. by 69 ft. 3 in. by 39 ft. to upper deck; deadweight capacity, about 18,000 tons. Single-shaft arrangement of double-reduction geared steam turbines of Pametrada design, developing a total of 7,500 s.h.p. in service. Steam supplied by two oil-fired water-tube boilers. Speed, 14½ knots. Launch, August 19.

M.V. " DESPINA C."—Single-screw cargo vessel, built by Bartram and Sons, Ltd., Sunderland, for the West African Steamship Co., Monrovia, Liberia. Main dimensions: 445 ft. between perpendiculars by 62 ft. by 40 ft. 2 in. to shelter deck; deadweight capacity, 10,750 tons on an extreme draught of 26 ft. 11¼ in. N.E.M.-Doxford five-cylinder opposed-piston oil engine, developing 5,500 b.h.p. at 115 r.p.m. in service, constructed by the North Eastern Marine Engineering Co. (1938), Ltd., Wallsend-on-Tyne. Engine designed to operate on heavy fuel or Diesel oil. Service speed, 14½ knots. Launch, August 23.

H.M.S. " TIDEREACH."—Fast replenishment oil tanker, built and engined by Swan, Hunter, and Wigham Richardson, Ltd., Wallsend-on-Tyne, for the Admiralty, London, S.W.1. Sister ship to H.M.SS. Tiderace and Tiderange. Main dimensions: 580 ft. overall; 70 ft. in beam; load displacement about 32 ft.; cargo-carrying capacity, about 15,000 tons. Powered by double-reduction geared steam turbines, capable of developing 15,000 s.h.p. and giving a maximum speed of over 18 knots. Accepted by Royal Navy, August 30.

H.M.S. " LULLINGTON."—Twin-screw coaster minesweeper, built by Harland and Wolff, Ltd., Belfast, for the Admiralty, London, S.W.1. Main dimensions: 152 ft. by 28 ft. 9 in. by 14 ft. 9 in.; armament, three small guns. Diesel propelling machinery supplied by Mirrlees, Bickerton and Day, Ltd., Stockport, Cheshire. Launch, August 31.

H.M.S. " DOWNHAM."—Inshore minesweeper, built by J. Samual White & Co., Ltd., Cowes, Isle of Wight, for the Admiralty, London, S.W.1. One of a series of vessels having a length of 106 ft. 5 in. and a breadth of 20 ft. 6 in. These warships are of all-wood construction and are designed to operate in shallow inland waters. Launch, September 1.

ENGINEERING, MARINE AND WELDING EXHIBITION

AND THE FOUNDRY TRADES EXHIBITION OLYMPIA, LONDON SEPTEMBER 1—15

Fourth Article

This week has seen the closing of the exhibition which has drawn a steady stream of visitors. We would like to take this opportunity of repeating a request made earlier by the organisers—F. W. Bridges and Sons, Limited, Grand Buildings, Trafalgar-square, London, W.C.2. During the war they lost some of their records and they ask firms which have exhibited since 1906 to inform them so that their lists may be complete.

In this article we continue our descriptions of some of the exhibits.

BLED STEAM TURBO-GENERATOR

In addition to the exhibits on the stand of Messrs. W. H. Allen, Sons and Company, Limited, Bedford, of which a description was given on page 276, *ante*, mention may be made of the mixed-pressure geared turbo-alternator for ships work, which was being shown by the same firm.

This machine, which is illustrated in Fig. 45, consists of a turbine which is arranged to operate on steam bled from the main propulsion turbines of the ship at a pressure of 47 lb. per square inch absolute and a temperature of 350 deg. F. Under these conditions it will generate 400 kW and, in addition, drive the main boiler feed pump, which is of Weir construction and requires 210 b.h.p. at normal load. On the other hand, when supplied with steam at a pressure of 570 lb. per square inch and a temperature of 620 deg. F. it will generate 550 kW and will supply up to 265 h.p. for driving the feed pump.

It is mounted on a surface condenser with an area of 1,483 sq. ft., which is designed to give a vacuum of 28 in. with a sea-water temperature of 82 deg. F. Its speed is 8,000 r.p.m. and it drives the alternator at 1,800 r.p.m. through single-reduction double-helical gearing. The speed of the feed pump is 4,250 r.p.m.

As regards design the turbine is of the impulse type with eight Rateau wheels and is equipped with four groups of main nozzles. The first three of these receive the low-pressure steam through separate nozzle-control valves, and the fourth high-pressure steam through another valve. All four control valves and the two emergency valves through which the steam passes and which are normally wide open, are operated by oil-relay cylinders. These cylinders are arranged with their centre-lines horizontal, thus assisting ventilation and reducing the risk of fire.

The governor is of the leverless type, control being effected by opening the valves in the first three nozzle groups in turn as more power is required. When all these valves are fully open and the set is unable to maintain the required output, high-pressure steam is admitted through the fourth nozzle group. An automatic thermostat is provided on the high-pressure gland, so that the sealing steam does not require adjustment with the changes in load. The auxiliary oil pump is arranged to supply pressure oil to the relay cylinders of the throttle and emergency valves so that the latter can be opened during starting. In fact, the emergency valves can only be opened in this way so that it is impossible to start the turbine without running the auxiliary oil pump and automatically flooding the bearings.

The alternator, which is designed for parallel operation is of the ventilated, drip-proof, salient-pole type and has an output of 550 kW at 450 volts 60 cycles when running at 1,800 r.p.m. Main and pilot exciters are flexibly coupled to the alternator shaft, the latter being of the permanent-magnet alternating-current type, the output of which is rectified to 110 volts. Voltage regulation is effected by an automatic regulator of the carbon-pile type in the field of the main exciter. There is also a hand-operated regulator for stand-by purposes. Forced lubrication is employed.

BARRIER CREAMS

As more materials are coming into use, the possible dangers to health are increased. Dermatitis used to be frequently met with in many industries, but can now be largely prevented by the use of suitable barrier creams. On their stand at the exhibition, Rosalex Limited, 10 Norfolk-street, Manchester, 2, were displaying a wide range of such creams that have been developed for different applications. In the main they can be divided into two types, the true " barrier " that is applied before commencing work and the " after work " ointments to counter dehydration, fat-removal or chafing.

Of the barrier creams, types have been produced to give protection against dusts or oils and acids or organic solvents. Some are intended for the food industry and their ingredients cannot cause any contamination. Others have been made to be used for processes where a group of irritants may be encountered and others again for a single specific chemical. Of the two " after-work " creams, one is intended to replace lost fat in cases where there is also a slight water loss, and the other is for use when the skin is roughened or chafed. The former also gives some protection against ulceration of the lips or nasal passages due to the inhalation of acid fumes.

CENTRALISED LUBRICATION

Among the equipment exhibited by Benton and Stone, Limited, Aston Brook-street, Birmingham, 6, was a range of pneumatic equipment, including air cylinders from ¾ in. to 6 in. in diameter, and valves and fittings of various types. They also had on show examples of their centralised lubricating systems, including a re-designed " one-shot " lubricator, which can be operated by hand in the normal way, or by a built-in air cylinder. This lubricator is basically the same as the well-known " Enots " combined pump and oil reservoir, but incorporates improvements both in appearance and in operation. The new unit consists of an oil reservoir of modern style, with two fixing holes at 3⅞ in. centres by means of which it can be fixed in any convenient position on a machine. A quick-action filler cap and strainer are fitted to the top of the reservoir. The pump is mounted on the centre-line of the reservoir, with the handle at the bottom. The handle can be at the front, as shown in the illustration, Fig. 46, or at either side.

Pumps are available with capacities of 0·5, 0·9, and 1·8 cub. in. per stroke, and the reservoirs can be of 1, 2 or 4 pints capacity. The outlet for the lubricant is at the side of the reservoir at the top. It is designed for use with ⅛-in. outside-diameter tubing and solderless fittings; a range of these tubes and fittings is also on display on the company's stand. The pump delivers oil under pressure to the distributors and metering chambers, which are mounted as close as possible to the bearings they serve. Any number of distributors can be used, within the capacity of the pump, and they are available to serve 1, 2, 3, 4 or 6 bearings each. The distributor has a metering chamber of suitable capacity for its bearing, this being calculated on the basis of providing 0·001 cub. in. of oil per square inch of bearing surface area. Oil from the pump enters each distributor and fills the metering chamber, compressing air at the top. A state of equilibrium being reached, the pump handle cannot be moved further, and on its release pressure in the main oil line drops. The valves in the distributor then allow the air

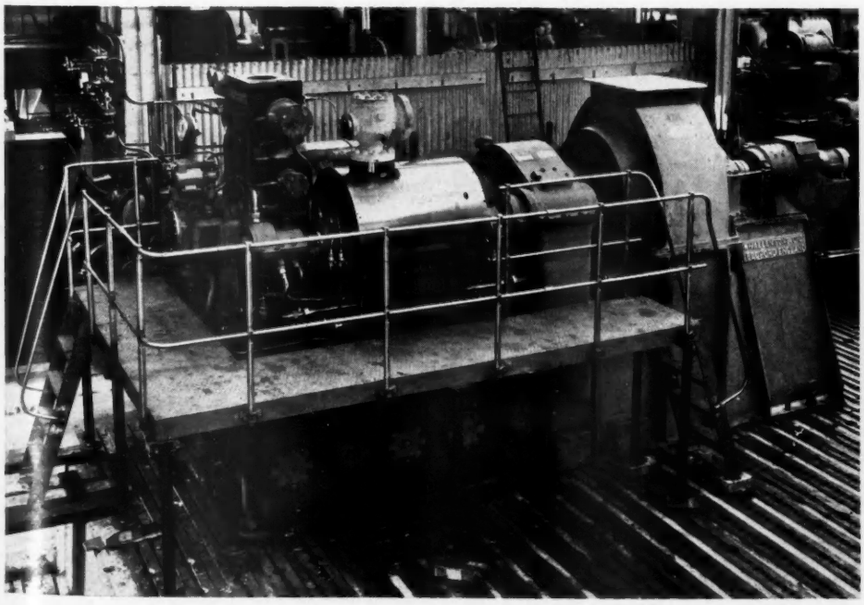


Fig. 45 550-kW self-contained marine-type mixed-pressure geared turbo-alternator. W. H. Allen, Sons & Co. Ltd.

Exhibits Described

Bled Steam Turbo-Generator	*W. H. Allen, Sons & Co., Ltd.*
Barrier Creams	*Rosalex Ltd.*
Centralised Lubrication	*Benton and Stone, Ltd.*
Isotope Radiography	*Gamma Rays, Ltd.*
Air Filtration	*Air-Maze Ltd.*
Self-Exciting Alternators	*Tuscan Engineering Co., Ltd.*

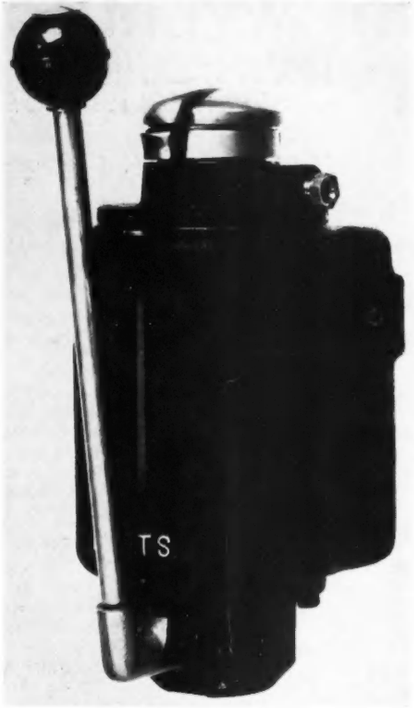


Fig. 46 The redesigned "Enots one-shot" lubricator is available in several sizes. The pump handle can be fitted at the front or at either side. Alternatively, the pump can be operated by an air cylinder, with remote or grouped control. Benton & Stone, Ltd.

compressed in the metering chamber to force the oil through a short run of ¼-in. outside-diameter pipe to the bearing. A by-pass valve in the pump-plunger body allows oil which has been displaced by the return of the distributor valves to return to the reservoir, and ensures that the pump makes a full suction stroke when the handle is operated.

A new feature of the "one-shot" lubricator is the provision of means for compressed air operation. By removing the pump handle and its mounting from the bottom of the oil reservoir a small compressed air cylinder can be fitted in its place. The operation of the pump can then be controlled by an air valve of the push-button type from any convenient point. It is also possible to combine any number of lubricators into one group controlled by a single push-button, or to arrange, if desired, for the lubrication of any group of machines to be fully automatic. The only manual attention then required would be the occasional replenishment of the oil in the reservoir.

ISOTOPE RADIOGRAPHY

As more and more radio-active isotopes become available, so the number of instruments for using them in industry also increases and Gamma-Rays, Limited, Foundry-lane, Smethwick 40, Staffordshire, had a large selection on their stand. The central item was their new industrial unit which has been produced for cobalt sources up to a strength of 20 curies and for caesium up to 2,000 curies. This equipment is designed to compete with high-voltage X-ray plant both as regards exposure time and cost. Running expenses are small and there is no tube to be replaced. Being a high-capacity machine it would be installed in a separate room and remotely controlled. Safety devices ensure that any breakdown would cause a "failure to safety." All exposures are controlled by an electric time clock and steel sections 12 in. thick require only a few moments even when fine grain film is being used. Transportable models were also on show for cobalt sources of 3 curies, 600 millicuries and 250 millicuries.

PIPE-LINE EXAMINATION

Another new unit displayed was one for iridium-sources with strengths up to 5 curies. One of these, affixed to a pipe, is shown in Fig. 48. This model was originally designed for the examination of the pipe line between Sui and Karachi in Pakistan. The film is contained in a flexible cassette which is held against the far side of the pipe by the tension clamp. The resultant picture therefore shows both walls and a special technique is required in reading it. As will be seen from the illustration, the source is exposed by rotating a lever on the top of the container, and an indicator panel shows whether it is open or shut. Apart from its use on pipe lines—for which it is suitable for sizes of 6 in. outside diameter and upwards—it can be mounted on a stand and used for general work. Being small in size, it can conveniently be used for small internal work.

An alternative method of examining circumferential welds in pipe lines is made possible by a spider mechanism which was also on show for the first time. It is shown, with guide arms extended, in Fig. 47. For insertion in the pipe, the arms are closed by means of the central rod and square-threaded screw, and also the bomb containing the source is closed. The spider can either be lowered along an inclined pipe, or pushed up to 40 ft. along a horizontal one. When in position opposite the weld, the arms are extended by rotating the central rod, and the source is thereby centralised in the pipe. A film cassette is wrapped completely round the exterior of the weld and the source exposed by means of the Bowden cable. The latter operates against a spring, so that in the event of breakage or other failure, the bomb closes and renders the spider "safe." With this device, a picture of the complete weld can be obtained by a single exposure, without the difficulties of the double-wall technique which occur when an exterior source is used. The spider is suitable for all pipe sizes between 6 in. and 18 in. inside diameter.

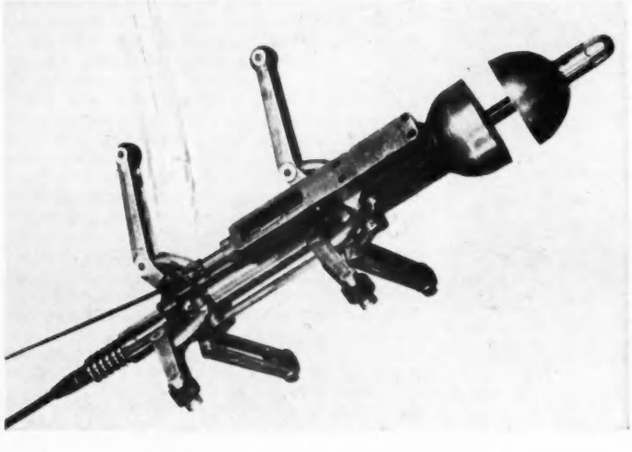


Fig. 47 Circumferential pipe welds can be examined completely in a single exposure by using a spider which carries the source inside the pipe. Gamma-Rays, Ltd.

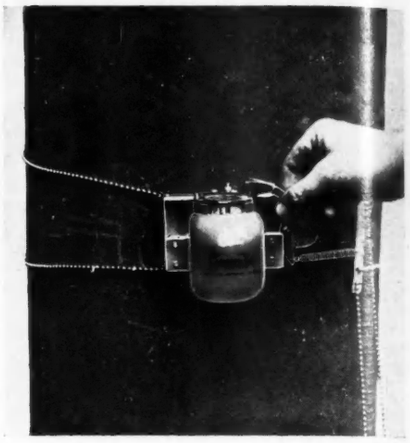


Fig. 48 An iridium source for examining pipe welds is clipped on to the exterior of the pipe and opened by hand as shown. Gamma-Rays, Ltd.

AIR FILTRATION

Air filtration is one of the specialities of Air-Maze, Limited, Church-street, Warrington, and they were showing two new products on their stand. The first was the "Electromaze" electric air filter; it is a two-stage electrostatic precipitator designed to remove 90 per cent. or more of all air-borne dust and particle impurities down to ⅓ micron from air used for controlled ventilation or industrial operations requiring optimum cleanliness. An Electromaze assembly consists of the required number of "Uni-cells", one of which is shown in Fig. 49, their holding frames and high-voltage power supply, all erected into a bank installed in an air duct. Each uni-cell has its own diffuser, ionising section, and collector plate section, all built into a single unit, making each cell a complete filter in itself which slides into its holding frame like a file drawer.

The power supply unit converts the standard mains supply at 230 volts alternating current to 10,000 volts direct current by means of a transformer and a rectifier. This high voltage is applied to both ionising and collector plate sections of the uni-cell. Dirt particles in the air stream passing through the uni-cell receive an electrostatic charge in the ionising section and are then attracted to the oppositely-charged parallel metal plates in the collector section. The plates are coated with a water-soluble oil adhesive which retains the attracted particles. Collected deposits are periodically removed by washing the uni-cells, which must then be re-oiled before replacing.

The second new product which was shown by Air-Maze, Limited, is the "Automaze" automatic self-cleaning air filter, shown in Fig. 50. It combines a double filter panel travelling curtain for the removal of air-borne particles and a self-cleaning mechanism using a "pulse-type" action. The filtering medium has an adhesive coating and is formed into panels or cells which are carried on an endless roller chain to present a double filtering barrier to the incoming air. The roller chain is mounted in a steel cabinet at the bottom of which is a tank containing a large supply of adhesive. The filter panels move up the front of the cabinet like a curtain, then over the top maintaining the same vertical position like a Ferris-wheel car. They move down the back to be submerged, agitated, and cleaned in the adhesive bath before travelling up the front again. The movement of the endless chain is accomplished by an air-driven piston actuated by an automatic electric time-cycle control system.

The pulsating movement of the air cylinder in moving the filter provides cleaning action of

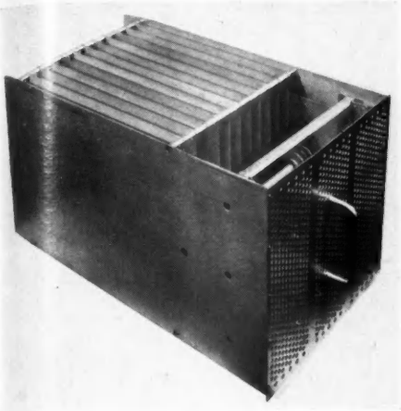


Fig. 49 The electrostatic air-filtration unit is made up of "Uni-cells," one of which is shown here. Each unit is complete in itself, and slides in and out of its supporting framework like a file drawer, making its removal and replacement a simple matter. Air-Maze Ltd.

the device. As the roller chain carrying the panels is moved by the air cylinder, the filter panel, immersed in the adhesive bath, swings backwards and forwards and clean adhesive is forced through the filter medium in both directions. The dirt particles are washed out and settle on the bottom of the tank from where they can be removed at intervals depending upon the contamination of the air passing.

SELF-EXCITING ALTERNATORS

Tuscan Engineering Company, Limited, Industrial Estate, Bridgend were for the first time exhibiting a range of self-exciting, self-regulating alternators, one of which is illustrated in Fig. 51. These machines are of the rotating armature type and are inherently self-regulating within ± 2½ per cent. of the rated voltage under normal operating conditions at unity power factor;

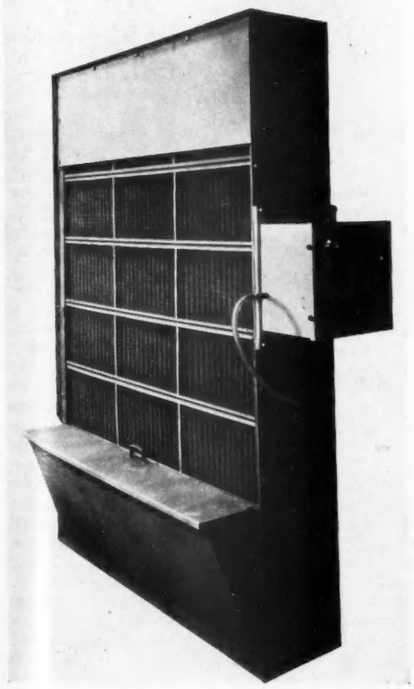


Fig. 50 An automatically self-cleaning air filter. The filter panels are carried round on an endless chain and are cleaned on each revolution in a bath of adhesive at the bottom of the unit. Air-Maze Ltd.

they have been specially designed for small power or house lighting plants and close consideration has been given to robustness in construction and protection from moisture and dirt. The brush gear, while completely protected, is also readily accessible and the alternating and direct-current brushes can both be easily removed and replaced.

At the present time the alternators are produced in two forms: with foot mounting for direct coupling or belt driving, or with a hollow shaft and single bearing for mounting on an engine crankcase. The output of these alternators ranges from 0·25 to 2·0 kVA and they are available for any standard single phase 50 or 60 cycle voltage.

In the first article on the exhibition, we published on pages 274-5 a note on the display of the Merlin Engineering Company, Limited. The text referred principally to the company's "Calimaster M6" and the caption to Fig. 7, describes the machine illustrated as the M6;

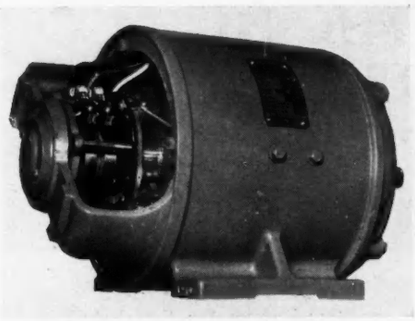


Fig. 51 Self-exciting, self-regulating alternator. Tuscan Engineering Co. Ltd.

the illustration is, however, of a heavier model, the M8, which was also at the exhibition.

To be continued

NOTICES OF MEETINGS

Association of Supervising Electrical Engineers

BIRMINGHAM
Visit to B.B.C. Television Station at Sutton Coldfield. Birmingham Branch. Sat., Sept. 24, 3 p.m.

CANTERBURY
"Space Heating," by E. M. Ackery. Kent Branch. County Hotel, Canterbury. Thurs., Sept. 22, 8 p.m.

PORTSMOUTH
"The Preparation of Electrical Specifications," by H. J. Meader. Portsmouth Branch. "Air Balloon," 596 Commercial-road, Mile End, Portsmouth. Tues., Sept. 20, 8 p.m.

British Institution of Radio Engineers

LONDON
"Extending the Limits of Resistance Measurement using Electronic Techniques," by G. I. Hitchcox. London Section. London School of Hygiene and Tropical Medicine, Keppel-street, London, W.C.1. Wed., Sept. 28, 6.30 p.m.

Building Centre

LONDON
Film, "Taking the Load" (Handling Materials on Site). Wed., Sept. 21, 12.45 p.m.

Engineers' Guild

LONDON
Annual General Meeting. Metropolitan Branch. Caxton Hall, Westminster, S.W.1. Thurs., Sept. 22, 6 p.m.

Illuminating Engineering Society

BATH
"Interior Decoration and Its Effect upon Illumination," by J. D. Layton. Bath and Bristol Centre. Offices of the South Western Electricity Board, Old Bridge-street, Bath. Fri., Sept. 23, 7 p.m.

BIRMINGHAM
Chairman's Address, by G. R. Hanson. Birmingham Centre. Regent House, St. Phillip's-place, Colmore-row, Birmingham. Fri., Sept. 23, 6 p.m.

LEEDS
Trotter-Paterson Memorial Lecture on "The Brightness of the Stars," by Sir Harold Spencer Jones. Leeds Centre. Chemistry Lecture Theatre, The University, Leeds. Mon., Sept. 26, 7 p.m.

LEICESTER
"Interesting Lighting Jobs." Various short papers. Leicester Centre. Offices of the East Midlands Electricity Board, Charles-street, Leicester. Mon., Sept. 26, 6 p.m.

Incorporated Plant Engineers

BIRMINGHAM
"The Do's and Dont's of Refrigeration," by M. E. Lea. Birmingham Branch. Imperial Hotel, Birmingham. Fri., Sept. 30, 7.30 p.m.

CARDIFF
"Space Heating," by W. M. Barber. South Wales Branch. South Wales Engineers' Institute, Cardiff. Tues., Sept. 27, 7.15 p.m.

LEEDS
"Axial Flow Fans," by R. H. Holbeche. West and East Yorkshire Branch. Leeds University. Mon., Sept. 26, 7.30 p.m.

SHEFFIELD
"Steelmaking and the Plant Engineer," by R. Mayorcas. Sheffield and District Branch. Grand Hotel, Sheffield. Thurs., Sept. 29, 7.30 p.m.

Institute of Physics

LONDON
"Some Recent Developments in Magnetic Materials," Symposium. Electronics Group. Fri., Sept. 23, 3.30 p.m., and Sat., Sept. 24, 10 a.m.

Institute of Road Transport Engineers

DURHAM
"Gas Turbine Development for Road Transport," by P. A. Phillips. North Eastern Centre. Three Tuns Hotel, Durham City. Tues., Sept. 27, 7 p.m.

Institution of Engineering Designers

LONDON
"Automatic Control," by P. J. Booker. London Branch. Wed., Sept. 28, 7 p.m.

Institution of Locomotive Engineers

LONDON
Presidential Address, by K. J. Cook. Institution of Mechanical Engineers, 1 Birdcage-walk, St. James's Park, S.W.1. Wed., Sept. 21, 5.30 p.m.

Institution of Production Engineers

LONDON
"Industrial Gases with Particular Reference to Oxygen and Acetylene," by F. D. Hucklesby. London Graduate Section. Wed., Sept. 21, 7.15 p.m.

BIRMINGHAM
"Material Utilisation," by R. M. Evans. Midlands Section. The James Watt Memorial Institute, Great Charles-street, Birmingham. Wed., Sept. 21, 7 p.m.

CARDIFF
"Extrusion of Metals," by J. T. Lewis. South Wales and Monmouthshire Section. The South Wales Engineers' Institute, Park-place, Cardiff. Fri., Sept. 23, 7 p.m.

LUTON
"Materials Handling," by K. B. Warwick. Luton Section. Queens Works of W. H. Allen, Sons and Co., Ltd., Bedford. Tues., Sept. 27, 7.30 p.m.

MANCHESTER
"Lubrication," by Dr. H. E. Priston. Manchester Section. College of Technology, Sackville-street, Manchester. Mon., Sept. 19, 7.15 p.m.

NEWCASTLE-UPON-TYNE
Chairman's Address, by F. Baker. North Eastern Section. Neville Hall, Westgate-road, Newcastle-upon-Tyne. Mon., Sept. 19, 7 p.m.

SHEFFIELD
Practical Lecture on "Screw Thread Gauging." Sheffield Graduate Section. Inspection Establishment, Janson-street, Sheffield. Mon., Sept. 19, 6.30 p.m.

Institution of Works Managers

GLASGOW
Film, "Capacitors Pay Dividends," with commentary by H. Ferguson. Glasgow Branch. The Institution of Engineers and Shipbuilders in Scotland, 39 Elmbank-crescent, Glasgow, C.2. Mon., Sept. 19, 7.30 p.m.
"Management Accounting," by W. G. Scott. Paisley Group. Eadie Brothers & Co., Ltd., Paisley. Wed., Sept. 21, 7.15 p.m.

LIVERPOOL
Annual General Meeting. Merseyside Branch. The Adelphi Hotel, Liverpool. Tues., Sept. 20, 6.30 p.m.

NORTHAMPTON
Annual General Meeting. Northampton Branch. Franklins Gardens Hotel, Northampton. Tues., Sept. 27, 7.45 p.m.

WOLVERHAMPTON
Annual Dinner. Wolverhampton Branch. Molineaux Hotel, North-street, Wolverhampton. Tues., Sept. 20, 7.30 p.m.

Royal Aeronautical Society

LONDON
"The Growth of Aeronautical Research in Canada during the Post-War Decade," by Dr. J. J. Green. The Eleventh British Commonwealth and Empire Lecture. The Royal Institution, 21 Albemarle-street, London, W.1. Thurs., Oct. 6, 6 p.m.

The address and telephone number of the headquarters of each institution are given below. Meetings in the headquarters town are held there unless otherwise stated. Particulars for this column should reach the Editor not later than Monday morning in the week preceding the date of the meeting.

Association of Supervising Electrical Engineers, 23 Bloomsbury-square, London, W.C.1. (LANgham 5927.)
British Institution of Radio Engineers, 9 Bedford-square, London, W.C.1. (MUSeum 1901.)
Building Centre, 26 Store-street, London, W.C.1. (MUSeum 5400.)
Engineers' Guild, 78 Buckingham-gate, London, S.W.1. (ABBey 7315.)
Illuminating Engineering Society, 32 Victoria-street, London, S.W.1. (ABBey 5215.)
Incorporated Plant Engineers, 48 Drury-lane, Solihull, Birmingham. (Solihull 3021.)
Institute of Physics, 47 Belgrave-square, London, S.W.1. (SLOane 9806.)
Institute of Road Transport Engineers, 69 Victoria-street, London, S.W.1. (ABBey 6248.)
Institution of Engineering Designers, 38 Portland-place, London, W.1. (LANgham 8847.)
Institution of Locomotive Engineers, 28 Victoria-street, London, S.W.1. (ABBey 6672.)
Institution of Production Engineers, 10 Chesterfield-street, London, W.1. (GROsvenor 5254.)
Institution of Works Managers, 67-68 Chandos-place, London, W.C.2. (TEMple Bar 8324.)
Royal Aeronautical Society, 4 Hamilton-place, London, W.1. (GROsvenor 3515.)

THE HUMAN ELEMENT

Avoiding breakdown of negotiations in industrial disputes; no approval from the unions for removal of wage restraint; but the French remove wage restraints; the N.C.B. and the N.U.M. investigate coal production; a drive to improve health in factories; Mr. Tiffin on hopes and responsibilities.

* * *

New Powers for the T.U.C.

At Southport last week the Trades Union Congress gave its general council power to intervene in industrial disputes before negotiations have broken down. The council's efforts to get the constitution amended to give it more flexibility in dealing with disputes were thus successful. It was no sweeping victory, however. Four powerful unions—engineering workers, railwaymen, electricians and woodworkers—led an opposition of three million votes.

Opposition to giving the council further power was of two kinds. There were the large unions which do not wish their bargaining position in their pending wage negotiations to be damaged by the employers manoeuvring them into a position where the T.U.C. has to be called in quickly. The A.E.U. and the N.U.R. are obviously anxious about this possibility. Secondly, there are the small unions who fear having their affairs too quickly influenced by the large unions who inevitably dominate the T.U.C.

It was therefore a very convincing Mr. Campbell, general secretary of the N.U.R., who took the rostrum from among the members of the general council on the platform to oppose the general council's motion. In the event, the delicate manoeuvring finished up in favour of the council. But the issue remains a difficult one for the T.U.C. and the unions. The strength of either side's case depends on the personalities involved. An over-anxious or inept T.U.C. could clearly speed up a breakdown in negotiations between the employers and the union concerned. On the other hand, starting from a position of deadlock is an awkward legacy for the T.U.C. to handle, for once each party in a wage dispute has taken up what it has announced to be its final position, loss of face becomes almost as big an issue as loss of the claim. New words have now been written into the constitution: great tact and ingenuity will be required to ensure that the change has the desired effect.

* * *

The Unions on Wage Restraint

Whereas the general council's attitude on its increased powers to intervene in industrial disputes achieved no more than a respectable majority, its attitude on wage restraint received more convincing support. The reasons for this were not far to seek. Many delegates had genuine misgivings about surrendering any flexibility to the central executive. On wage restraint, however, a familiar battle-order was followed in which each man knew his stance before the battle commenced. The resolution to remove any form of wage restraint was put by a member of the Communist Party on behalf of the Electrical Trades Union. The motion was a dangerous one for the general council, for it would have committed them to support all efforts of its member unions to improve wages and conditions. It was lost by a comfortable margin, following a series of responsible speeches, among which that of Mr. W. J. P. Webber of the Transport Salaried Staffs Association was outstanding.

Success for moderation was almost followed by defeat in a significant skirmish on overtime. A motion for a reduction of systematic and excessive overtime and for the 40-hour week was defeated amid confusion and misunderstanding among the miners' delegates, whose voting power would have been sufficient as the counting turned out to have swung the vote the other way. Such an outcome could of course have given scope for endless mischief-making by those in the trade union movement who have a mind to do so, but the incident came as a timely reminder that the annual conference of the T.U.C. is after all a matter for men and not for machines.

* * *

French Contrast

France is going its own way to solve the problem of how to prevent higher wages from generating inflation. Whereas Britain and Germany, faced with a similar problem, are trying to restrain wage demands and prevent the public's purchasing power putting too great a strain on their country's resources, at the same time trying to keep the cost of living in check, France is adopting quite a different procedure. The Government has now said that it is not averse to higher wages and is also encouraging private investment. The official view is that there is no need yet for anti-inflation measures.

Conditions in France are, of course, not identical with those in either Britain or Germany. France has a food surplus to market, the public are not spending as freely as they are in this country, exports are keeping pace with imports, the gold reserves are improving and prices have been remarkably stable of late. On the other hand, the national budget still carries a chronic deficit, France's competitive power is hindered by its high costs and prices and there is a large public investment programme taking shape.

Against this background French labour is lining up further wage demands, among which those from the engineering operatives are playing a prominent part. There are thus three schools of thought in western Europe at the moment on how to deal with wages and prices. The British are relying on monetary controls, the Germans on freer imports, and the French are taking the lid off. It remains to be seen which prescription is most successful.

* * *

Joint Coal Investigation

An agreement has been reached between the National Coal Board and the National Union of Mineworkers for a joint pit-to-pit investigation into the decline in coal production. It has not been decided what form this survey will take, but if, as has been suggested, union leaders are to probe no further than divisional level, the scheme is not likely to achieve any very striking results. The Coal Board is clearly in a quandary now that the miners have rejected the introduction of more foreign labour. The miners have found themselves in the position of having to make a constructive offer to overcome the industry's acute problems of wastage, recruitment and mobility of manpower. Last week the miners' president, Mr. W. E. Jones, went so far as to say that the union leaders faced the production situation " with the greatest apprehension."

There is reason for this concern. Looking at the coal figures for the week ended September 3, the latest period for which they are available, the results are bad. Whether the single week is compared with the same week a year ago, or the cumulative statistics for the first 35 weeks of this year are taken, nearly every figure for the current period is worse than for the comparative one. Output from the mines is down (though opencast output is up); manpower is down; voluntary absenteeism is worse; output per man-shift is lower; distributed stocks are a few thousand tons better than at this time last year. Meanwhile coal consumption continues to run at a higher level than at this time last year. Conditions such as these clearly indicate that the problem is urgent. If this joint investigation is to do any good it must be much more than a gesture of goodwill. It must be a genuine investigation and it must be immediate and thorough.

* * *

" Health in Factories " Survey

Halifax is to be the first of two towns chosen in connection with the pilot survey for the drive to be undertaken to promote health and well-being in factories. This drive is being carried out under the auspices of the Ministry of Labour and this particular survey is backed by the Industrial Health Advisory Committee under the chairmanship of the Minister himself. It is also supported by both sides of industry and the medical organisations. Before any systematic steps can be taken to improve health in factories, an investigation must be made to ascertain the needs in any particular place. This gives rise to the need for a study of the conditions and occupational hazards in each town. The committee has decided that the best way to obtain the facts is to do a series of local surveys. The first of these surveys will be an assessment from a team of factory inspectors within that area.

Halifax has been chosen because it is a medium-sized town with a variety of industries. Every factory in Halifax will be visited by one inspector or the team to look at such matters as cleanliness, overcrowding, heating, ventilation, lighting and so on. They will then consider the need for preventive measures and, where necessary, medical and nursing supervision. A local advisory committee will be formed from employers' and union representatives to advise the inspectors. Results of the investigation will be forwarded confidentially to the Chief Inspector of Factories. If there is shown to be a need for the adoption of preventive measures in factories, individual cases will be followed up by the local inspector. Arrangements for the second survey have not yet been completed. Sir George Barnett, Chief Inspector of Mines, remarked at the inaugural meeting in Halifax that although much could be done at the national level, the main initiative and enthusiasum would have to be local.

* * *

Hopes and Responsibilities

Mr. A. E. Tiffin is still running himself in as general secretary of the Transport and General Workers' Union, and his public pronouncements, both as to what he says and when he says them, are of particular interest. Any man who follows in the footsteps of Ernest Bevin and Arthur Deakin inherits a large legacy—not to say a complicated one as well. In the September issue of the *Transport and General Workers' Record* Mr. Tiffin has contributed an article called " Preparing for the Future." The issue concerned came out last week, so Mr. Tiffin's thoughts, although printed in London, were beamed from Southport.

The article deals with a number of subjects in its review of the recent past and the problems of the future. Mr. Tiffin, as one would expect, does not like wild-cat strikes, unnecessary or badly organised overtime or (for obvious reasons) the recent dock dispute in northern ports. These three matters are all issues which have had to be dealt with in the last year or so.

So far as the future is concerned, he would like to see more coal and better roads, both of which require large amounts of capital for their development. He does not like the present Government's policy of using higher interest rates to curb expenditure, for he considers that such a policy will equally deter capital expenditure, which he would consider to be retrogressive. Like everyone else, he has high hopes of cheap fuel and power from nuclear energy which, along with higher productivity (and automation?) he expects to lead to a much higher standard of living. Such thoughts lead him " to wonder if wage claims with the lid off are in future going to be the answer to the search for a life of comfort and security." Since this is his closing thought, one imagines that he did not wonder for long.